THE FUNDAMENTALS OF Aviation

by Henry Lionel Williams

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Foreword

In the tragic years of World War II, millions of men and women throughout the world have been intimately concerned with the business of making or flying airplanes. Millions more have had the potentialities of air transportation forced upon their attention, too often under unhappy circumstances. Today, all the world knows the airplane, and there are few who do not recognize its tremendous possibilities for good as well as evil, for commerce as well as destruction, for the preservation of peace as well as the prosecution of war. In the days to come, many will wish to know more of this infant giant of aerial transportation that is fated not only to change the way of life of peoples all over the globe, but to reach more intimately into the lives of all of us.

The modern airplane is a safe and reliable vehicle of the air which promises quickly to become as important a necessity to many as their automobiles are today. But the air will not belong solely to the airplane. Other kinds of aircraft, too, will have their place in the public and private transport fields. Airships and rotary-wing aircraft have their advantages for specific purposes which the airplane cannot take away. Interest in these also will grow as they are developed. Meanwhile, the airplane holds the center of the stage. The eyes of those who have flown and those who wish to fly are focused principally on the light plane, which will not only provide personal transportation for many, but will create jobs for many more.

To properly appreciate these things, a little knowledge is not enough. In estimating the trends of future developments it is necessary to look to the past, to observe the difficulties that have been overcome as well as those that remain. This book, it is hoped, will serve to shed a little light on the origins of the various answers to man's attempt to navigate the great ocean of air; to point out the possibilities for the future, and the problems that still await

solution; to display, briefly, the broad picture of the conquest of the air, and the basic factors of air transportation which take into account not only the machines which fly, but the way they are flown, and the rules which, in this country, govern their flight.

Aviation is now so much a part of all our lives, and so revolutionary is its nature, that everyone cannot but benefit from knowing the fundamental facts of the developments and achievements out of which the Air Age has finally sprung.

C. S. (CASEY) JONES, *President,*
Academy of Aeronautics

CHAPTER I

How Men Learned to Fly

FOR the past two thousand years men all over the world have dreamed of navigating the earth's great ocean of air. Here and there, brave and reckless souls made attempts to emulate birds. Quite often the things they did were foolish and impractical, and, more often than not, fatal. But as time passed, men grew wiser. They learned from one another's mistakes, and they took fewer risks. They observed that even birds have to learn to fly, and that when the problem of rising in the air is solved, they still need to know how to control their flight. They found that the air is not a motionless fluid but a rough ocean, treacherous and unstable.

In the late eighteenth century, the subject of aerial navigation became divided into two branches—one employing aircraft lighter than air, the other making use of motion to sustain craft heavier than air. Out of the former came balloons and airships, and from the latter the heavier-than-air aircraft of all types. To avoid confusion, it may be better to review each of these separately and to begin with the airplane, which goes back to the first experiments with wings.

No one man invented the airplane. The first flying machines were the result of the work, the theories, experiments, and sacrifices of many men. Little by little, each added to the common store of knowledge—from Leonardo da Vinci, the fifteenth-century Italian genius who devised ornithopters and helicopters; Sir George Cayley, who, in 1800, sent his hapless coachman on a 900-foot glide; William Samuel Henson, with his aerial steam carriage; John Stringfellow, whose model plane flew 120 feet in the year 1848; Francis Hubert Wenham, who established principles with his flying "venetian blind"; the Frenchman, Penaud, who made flyable models with twisted rubber engines; Horatio Phillips, who built a multiplane to prove his theory of camber; Sir Hiram Stevens Maxim, an American-

born inventor living in England, who spent a fortune experimenting with giant planes, to Otto Lilienthal, who, beginning in 1871, made over 2,000 glides, and lost his life in the last one. All these and many others, including Clement Ader, with his "flying bats,"

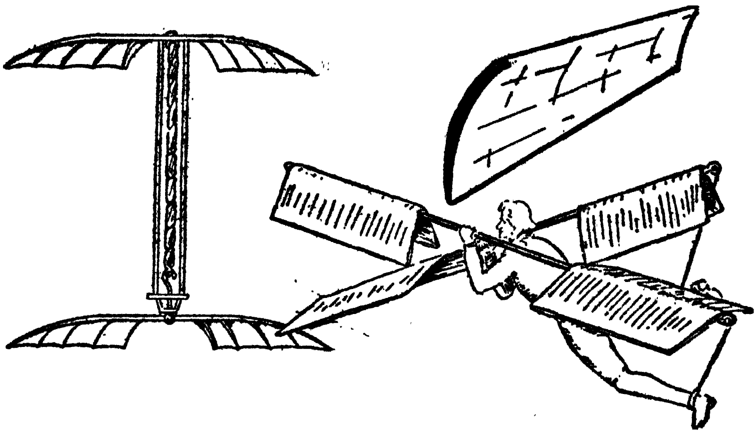


FIG. 1—Left: Penaud's helicopter; Upper right: Sir George Cayley's suggested arched wing; Lower right: Besnier's apparatus

and the great glider experts, Pilcher and Chanute, brought flying machine theory to such a point that S. P. Langley and the Wright brothers had available to them a vast background of practical data on which to work.

How close many of these early experimenters came to foretelling the structural features and principles of modern planes is little short of astounding. In the earliest days, men tried to fly by copying birds, but they had little or no knowledge of mechanical principles or the strength of the materials and structures they used. History is full of stories of men who made themselves wings and jumped with them from great heights. Their first attempts were usually their last. Leonardo da Vinci was one of the first to point out the need of being able to balance the wings or machine in the air. He wrote that a man equipped with such flying apparatus "should be free from the waist upward in order that he might keep himself in equilibrium as one does in a boat." He also pointed out that "safety

lies in flying at a considerable height from the ground, so that if equilibrium be temporarily upset, there may be time and space for regaining it."

Da Vinci designed an ornithopter—a machine with wings that flapped like a bird's, and a helicopter, which had revolving horizontal vanes or propellers to lift it straight up in the air. He sketched bird wings, which contracted on the upstroke and expanded on the down beat, and a helicopter with a rotor vane 96 feet in diameter. But none of these could work because there was no source of power both strong enough and light enough to work them. That his principles were right he demonstrated by making tiny paper helicopters that spun in the air. He, too, first suggested the parachute.

But not all men were so well grounded in physics as da Vinci. So, through all these years of rash experiment and none-too-scientific theory, men gave their lives in daring attempts to conquer gravity. Then came the era of more scientific and thorough study of the mechanics of flight.

In England, during 1809 and 1810, Sir George Cayley made some of the first practical attempts to solve the problems of mechanical flight. Through his innumerable experiments, he established some of the principles of flying machine construction that are incorporated in airplanes even today. He pointed out that birds soar with outstretched wings, as well as flying by flapping them. He recommended that flying machines be constructed with rigid wings and that some other means be employed to pull them through the air. He stated that, in order to increase the lifting power of such wings, they should not be made flat from back to front but should be arched upward. He advised the use of an auxiliary plane to the rear of the wing in order to preserve equilibrium, and advised moving it to make the machine go up and down.

Like other experimenters of this same time, Cayley made successful gliders, but he could produce no powered machine that would fly because there was no suitable engine available. Even this did not stop him entirely, for he set to work to design an engine which was to operate by means of gunpowder explosions in a cylinder. However, nothing came of that experiment.

With a little more luck, W. S. Henson, who tried to put Cayley's theories into practice, might have succeeded in becoming the first air-mail carrier. Henson planned a huge machine of canvas and bamboo that would certainly have weighed a ton. It was to have a 30 horsepower (h.p.) steam engine driving two propellers located behind the main wing. In applying for a patent on this machine Henson described it as "an improvement in locomotive apparatus and machinery for conveying letters, goods, and passengers from place to place through the air." In the patent specifications he pointed out that a flat article thrown edgewise in a slightly inclined position will rise into the air until the force is expended, and if continuous power were exerted on it, it would continue to ascend "so long as the forward part of the surface was upward in respect to the hinder part."

When his rather ambitious plan failed to mature, Henson collaborated with Stringfellow in producing small models. Stringfellow designed and built a number of very small steam engines for these models. One of the engines developed 1 h.p., even though it weighed but 13 pounds.

In 1845, Henson and Stringfellow built a model monoplane, with two pusher propellers, that weighed 30 pounds. It had a tail plane but no rudder, and it was not stable enough to stay in the air. Propellers, in those days, were very simple, often consisting of wood—flat wooden boards twisted or warped at each side of the center which were narrowed to the width of the hub. An even earlier type consisted of fabric stretched over the ends of two crossed pipes or bars, as in Fig. 2, Left. Later in the same year, Stringfellow completed another steam-driven model weighing 8½ pounds. This model flew well, but a full-sized machine was never made.

A specialist in wing shapes at this time was F. H. Wenham, who showed that the long, narrow wing was the most efficient type. He not only recommended the curved wing surface, but also the placing of one wing over another to give greater lifting area with small over-all size—the principle of the biplane. The model he built had six wings, one above the other, like the slats of a venetian blind. What this device showed was that most of the lift in a wing is developed

in the front part, near to what we now call the leading edge.

This principle was developed later by Horatio Phillips, who also investigated wing shapes. He improved on the curved wing suggested by Gayley by creating one that had a "dipping front edge." This wing had pronounced camber near the leading edge, to take advantage of the upper surface lift—the principle on which all modern wings work. And this was in the year 1881! That Phillips

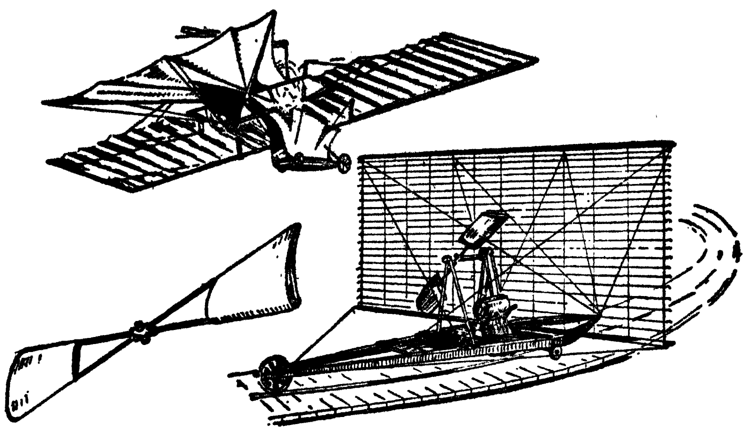


FIG. 2—Above: Henson's proposed flying machine; Left: Early type of propeller; Right: Phillips's experimental craft

recognized this principle is clear from his statement that "the rush of wind which meets the edge of the wing is spread out into two currents—one sweeping over the top and one below. The air current below the wing," he went on to say, "follows the curve and is thrust downward, thus imparting a lift to the wing." The upper current, meanwhile, rushes over the "hump" or camber, sweeping rearward so as to form a partial vacuum between the fast-moving air and the downward-curved surface. This "vacuum," he pointed out, has the effect of raising the surface of the wing, which is not only pushed up from below, but is drawn up from above. Anyone can check this theory by blowing over the top of a curved sheet of paper.

In order to prove that the front edge of a curved surface provides

most of the lift, Phillips built a machine which had fifty such surfaces 22 feet long and only 1½ inches wide. As the picture (Fig. 2, Right) shows, it looked like an oversized venetian blind. And the strange thing is that it worked! This contraption was fastened to a base which ran on a track, and had a propeller driven by a steam engine at 400 revolutions per minute (r.p.m.). The front wheel was fixed to the track, but the rear ones were free. The speed with which the device ran was sufficient not only to lift the rear wheels clear of the track, but to raise a 72-pound weight as well! Such a machine would not fly, of course, because there was no provision for controlling it in the air, but Phillips added greatly to our knowledge of how an airplane wing should work.

Failures as well as successes pointed the way to the first practical man-carrying airplanes. One of the most spectacular of such failures was the overly ambitious scheme of Maxim, who built a giant machine which, because of its engines, could never be anything more than an experiment. This huge contraption, based upon years of experimenting, had three wings, one above the other. The central and largest one had a span of 105 feet, bringing the total supporting surface to 6,000 square feet. To drive this machine, which was mounted on a rail just as Phillips's machine had been, two special 36 h.p. steam engines were used. These weighed only 640 pounds (about 1¾ pounds per h.p.), but they used so much water that they could only be run a few minutes at a time. The propellers they drove were of wood covered with canvas and were 18 feet in diameter.

This machine was successful insofar as it demonstrated that it could lift an enormous weight. It actually raised, as far as it was permitted to move, three men, 600 pounds of water, and a ton weight. In its final test it rose with such violence that it tore up the check rail which held it, and, becoming unmanageable, crashed.

Two important features of the Maxim machine were a horizontal plane located ahead of the wings to act as an elevator, and a vertical surface at the rear which served as a rudder for steering. The idea of the elevator was that, by tilting its front edge upward, it would lift the front of the wings, and this would give them more lift. Thus were developed two more devices used on modern planes.

Clement Ader, whom we mentioned earlier, was at this time experimenting along different lines, but with large machines also. These craft had wings like bats. The wings were light but unusually strong, being made of hollow wooden spars. They were deeply hollowed, shaped something like halves of an umbrella. On one of these machines they had a span of 54 feet. Control was effected

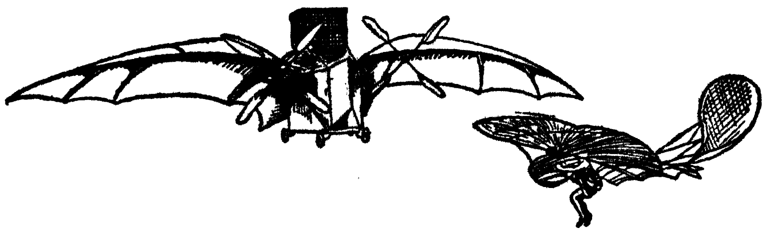


FIG. 3—Left: Ader's avion; Right: Lilienthal gliding

by varying the wing angle and by a rudder at the rear. Two 20 h.p. steam engines drove a pair of four-bladed propellers, the complete machine weighing 1,100 pounds. Running on wheels, this weird device actually flew, or leaped, about fifty yards, coming down with a crash.

Later, Ader built another machine of an improved type, with which he actually flew 300 yards. But, like so many others, this flight ended in grief because there was no adequate control. Yet Ader was actually the first man to fly in a powered aircraft, even though he could not repeat the performance. The lesson he left for those who followed was that a machine that will fly is not enough—the man who flies it must be able to control it under all the circumstances he is likely to encounter. In other words, he also must learn to fly. Herein lay the reason why progress in aviation was not faster in these pioneer days. So much time was involved, money was rarely plentiful, and in the end everything might be lost, with success just in sight, through a crash which destroyed the airplane and killed its designer.

Among the greatest names in pioneer aviation is that of the German, Otto Lilienthal, who, with his brother Gustav, built gliders

with which they made over 2,000 flights. What made their work so valuable to the men who came after them was the minute records they kept of their experiments and the scientific skill with which they conducted them. From 1871 to 1896, these experiments were carried out, beginning with bird wings and ending with a biplane glider that had a balancing tail. Throughout all these trials, the purpose behind them was to obtain sustained flight by the use of gravity for long enough periods so that proper control under all conditions could be learned. How difficult it was to do this will be evident when it is realized that many of the glides lasted no longer than one second; in five years Lilienthal was in the air no more than five hours!

In these trials he learned many things beside how to balance in the air. He found that the best amount of camber in a wing was one-twelfth of the width from front to back. He discovered that balance was effected by changing the center of gravity—and he made that change by shifting his weight. But often that change could not be made quickly enough to offset sudden gusts of air; some other method was necessary to quickly and automatically trim the glider to the changing air currents.

When all the possibilities of the small glider had been exhausted, Lilienthal built a biplane glider with a span of 18 feet, to give 100 square feet of supporting surface. At once he found that this was much more difficult to handle—much more sluggish in response, because his weight was so small in comparison with the weight and size of the glider. But with this glider he could go higher and farther, and glide in stronger winds, making good use of the tail surface and the rudder. Finally, the Lilienthal brothers decided they had solved the means of control, and now could install an engine to drive the craft.

Since no light engine was available, they decided to design one. But before this was accomplished, Otto undertook a last trial flight, after making a change in the rudder. Usually, he fitted a shock absorber so that, in case of accident, the glider would not be damaged by a fall. But he did not trouble to install it on this last flight. The wind was uncertain, and, as the glider gained altitude, it was

thrown out of balance. It fell from a height of 100 feet—and Otto Lilienthal died almost at once. But the work he had done was priceless to those who came after him.

Octave Chanute, after whom Chanute Field, Illinois, is named, took some of Lilienthal's ideas and improved upon them. Though born in France, he considered himself an American and made all of his 1,000 experimental glides here. He was among the first to incorporate movable parts in the wings to simplify and improve control.

At this same period, beginning in 1895, a man named Pilcher was experimenting along the same lines in England. Much that these men did was of great value to Samuel Pierpont Langley, a professor at the Smithsonian Institute, Washington, D.C. In 1896, Professor Langley built model airplanes with a 1 h.p. steam engine, which weighed 25 pounds. These models had one wing behind the other (we now call them tandem airplanes), with the wings set at a dihedral angle, i.e., sloping upward toward the outer ends or tips. This angle was to give them stability in flight. One of these models flew half a mile over the Potomac on several occasions. Another flew three quarters of a mile at 20 miles per hour (m.p.h.). A third, which weighed 30 pounds and measured 12 feet (across the wing tips) by 16 feet long, also flew nearly a mile. It had a steam engine developing 1½ h.p., which weighed about 7 pounds and turned two propellers in opposite directions at 1,200 r.p.m.

So successful were these experiments that the U.S. War Department gave Langley $50,000 to build a full-size plane. In 1903, Langley tried out his airplane, but misfortune after misfortune overtook him. The craft weighed 830 pounds and had a 52 h.p. gasoline engine. It was launched several times from a platform on top of a houseboat, loaded with a weight equivalent to that of a man, and each time it ignominiously fell into the water. But that the fault was in the launching and not in the design was proved in 1914, when Glenn H. Curtiss fitted it with floats and took off from the water in it, flying steadily and well. Langley was vindicated, but too late to do him any good for he had died long before, a disappointed man.

The year 1903 will long be celebrated as that in which man first made a sustained and controlled flight in a heavier-than-air machine. The men who achieved that distinction (for there were two of them) were the brothers Wilbur and Orville Wright. These men were bicycle mechanics by trade but scientists by inclination. Inspired by the work of Lilienthal, they began their glider experiments in 1900. In building their gliders they checked every theory before putting it into practice. They built a wind tunnel in which they tested wings of various shapes at different angles of attack. Soon they concluded that Lilienthal's problem of control was not one which could be solved by shifting weight to move the center of gravity. As Wilbur said later, "The center of pressure must coincide with the center of gravity—in actual practice they don't stay together for an instant."

This center of pressure to which Wilbur Wright referred is the point on a wing around which the air pressure is balanced, just as the center of gravity is the point around which the weight of the airplane is balanced. In a cambered wing, this center of pressure is normally about one third of the distance between the front (leading) and rear (trailing) edges. In flight, the center of gravity remains practically in the same position. But as the wing tilts or gusts strike it, the center of pressure moves, tending to throw the plane off balance. That change must be corrected instantly, often even as it occurs, if the smooth flight is to be preserved. The airplane, in fact, must constantly be balanced both sideways and fore-and-aft. This, the Wrights decided, must be done by control of the attitude of the glider.

An equally important problem which they faced was to get sufficient time in the air to study glider control. This problem they partially solved by building a glider light enough and big enough to be sustained by gentle breezes, which they flew as a kite. While the glider remained aloft, it was held by a rope while one of the men lying on the lower wing practiced balancing it. This glider was a biplane with a surface of 165 square feet, with a small horizontal plane, or elevator, ahead of the wings. The operator lay on the lower wing to cut down wind resistance, and held the cords which con-

trolled the elevator. By tilting the elevator up, the front of the glider was raised, which moved the center of pressure back and tended to make the glider rise. Tilting it down moved the center of pressure forward, and tended to make the machine glide toward the ground. This method, you will recall, was similar to that employed by Sir Hiram Maxim, and is used in a modified form on airplanes today.

To prevent the glider from dipping sideways, the Wrights evolved a method of increasing the angle of attack (the angle the wing surface makes with the direction of the wind). This was done by simply twisting that end of the wing up a little. Quick results were secured by twisting the other end down at the same time. This warping of the wing tips was also effected by a simple cord.

With these controls perfected, the Wrights tried launching the glider by having two men run with it, while the third man lay at the controls. Skids were fitted to permit it to slide along the ground on landing. In these short glides the controls worked well and landings could be made at 20 m.p.h. Thus encouraged, the Wrights built a much bigger glider, of 308 square feet. After tests which showed the need for reducing the wing camber, the brothers decided that the time had come to fit an engine to their machine. But first it was necessary to have more practice flights, in order to be able to meet all air conditions that might conceivably arise, instinctively and without thought.

In 1902, the first engine-powered airplane was built. The Wright brothers built the engine themselves. It was a four-cylinder, water-cooled type, of 25 h.p., that weighed 200 pounds. This engine was made to drive two light propellers, located behind the wings, by means of chains enclosed in tubes. In order that the propellers would revolve in opposite directions, one of the chains had to be crossed. The propellers were designed to revolve at about 450 r.p.m. The plane itself was practically identical in design with the brothers' latest glider. In front of the wings was a double elevator, and behind them a double rudder, the dual construction saving space and giving rigidity.

The controls of this first practical plane are interesting. In his

left hand the pilot holds a vertical lever which operates the elevators. Pulling this back, toward his body, raises the elevators and makes the plane rise. Pushing it forward causes the plane to descend. The pilot's right hand operates a similar lever, which controls both the rudder and the warping of the wings. Moving the rod backward or forward turns the rudder left or right, respectively. Moving the lever sideways pulls the warping wires to twist the wing tips, as desired. The pilot's feet are not used to operate any control.

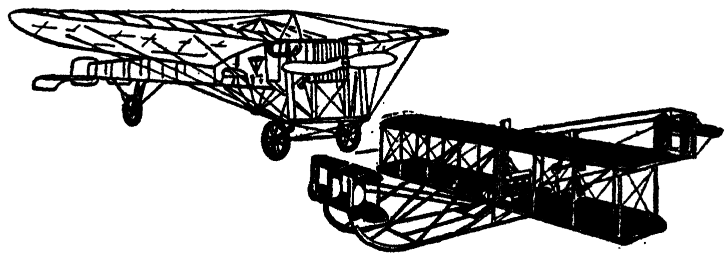


FIG. 4—Left: Bleriot monoplane; Right: The Wright biplane

To launch this airplane in the air, it was placed on an undercarriage running on rails. Its forward motion at the take-off was aided by the pull of a rope to which tension was applied by heavy weights supported by a derrick.

In taking off, the engine was speeded up until the propellers were turning fast. The weight was allowed to drop, pulling the plane forward at a rapidly increasing speed. At the end of the track, when it would be traveling at 30 m.p.h., the pilot would release the carriage and tilt the elevator, and the plane would rise in a gradual climb.

For two years after this, the Wright brothers did nothing but test this machine and practice maneuvers with it. In 1905, Wilbur Wright flew it for thirty-eight minutes, climbing, diving, turning with grace and ease. The first Wright plane had been perfected.

Meanwhile, in America and Europe, a dozen or more airplane builders were developing new and better airplanes. In France, the brothers Voisin towed gliders by motor car and motor boat, and from their experiments came a biplane, with vertical planes be-

tween the wings to check sideslip. For the Brazilian, Santos-Dumont, the Voisins first made a helicopter—a machine with propellers to lift it vertically from the ground—and then an airplane like a box kite. Later, they built a special biplane for one of the great pioneer pilots—Henri Farman.

By 1908, aviation events were beginning to move fast. In 1909, Louis Bleriot flew his tandem monoplane across the English Channel. Hubert Latham almost succeeded in doing the same thing, but his plane crashed into the water. Wilbur Wright took a Wright plane to France, and with his clumsy machine outflew the much neater French planes. However, his engine was heavy and inefficient, and he was handicapped by having to use a starting rail. This hindrance to cross-country flying was later removed by getting a more powerful engine and installing a wheeled landing gear.

This was the period of competing types, out of which the basic designs of modern airplanes were to develop. Some of these planes bore a remarkable resemblance to the ones of today. In plan view, Bleriot's monoplane, for instance, had a strangely modern wing. The Antoinette monoplane had a square-tipped, tapered wing. Santos-Dumont's box kite had dihedral; the Farman biplane had hinged balancing planes, or, as we now term them, ailerons, let into the wings.

This plane, too, had controls that later became standard on airplanes all over the world. A stick or lever, when moved forward or backward, operated the elevator. Moving it sideways operated the ailerons. The pilot's feet rested on a pivoted bar by which he turned the rudder. The landing gear, too, was novel, incorporating a shock-absorbing device. Two long skids below the lower wing extended fore and aft. Attached to these by a rubber cord was the axle of a pair of bicycle wheels. When the airplane rolled over the ground, the wheels, normally, took the weight. But in landing, if the shock was too great, the rubber cords allowed the wheels to rise so that the skids supported the plane. The skids then checked the forward speed of the plane before the wheels resumed their original position and allowed the plane to roll.

Also at this time, engine manufacturers began to design power

plants especially for airplanes, reducing the weight and increasing their reliability. Before this, the power plants had been adaptations of automobile engines, with the flywheel removed and the rest made lighter in various ways. Unfortunately, on the airplanes they were called upon to run at high speeds, under heavy loads, for considerable periods of time. Valve mechanisms and other small parts broke and the engines became overheated so that they could not deliver full power. The engines were heavy to begin with, and when the water-cooling system of pipes and radiators was added, together with the water, they introduced a serious amount of air resistance (drag) as well.

The earliest air-cooled engines gave trouble because they became very hot while the plane was being prepared for the take-off, and in the air the speed was not great enough to create the necessary draft. A big advance was made by the Gnome engine. This was an air-cooled engine with seven cylinders arranged radially around a crankcase. But unlike the ordinary radial engines, in which the cylinders remained stationary and the crankshaft revolved, it was the cylinders and crankcase that revolved. The propeller was attached to the crankcase and revolved with it. Thus, the cylinders were constantly whirled through the air, regardless of the speed of the plane, and better cooling was secured.

This engine enabled Farman to win a prize for the longest sustained flight. At this time—1909—the building of airplanes became established as an industry—Farman, Bleriot, Voisin in France, with Wright biplanes made under license in England. In the United States were the Wright brothers, and a very successful newcomer, Glenn H. Curtiss. The Curtiss machine was a small, light biplane powered by a Curtiss engine. Its novel features were a pair of ailerons mounted between the ends of the wings, and the method of controlling them. The control consisted of a back rest with arms. If the left end of the wings dropped, the pilot leaned toward the high end. This movement pushed the aileron control to the right and lowered the left aileron, which brought the plane level again.

Like the Wright brothers, Curtiss began as a bicycle mechanic, then designed and built motorcycle engines. Later, he built engines

for airships, and so became interested in airplanes. A major contribution which he made to the aviation industry was the building of the first airplanes to take off from water. During the First World War, he made the famous Curtiss JN4D's, or Jennys, with which so many American pilots earned their wings.

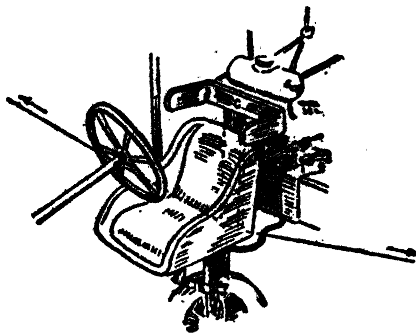


FIG. 5—Curtiss aileron control

And so the aviation industry was launched. Almost any intelligently designed airplane could be made to fly. There were big planes and little ones—monoplanes, biplanes, and triplanes, airplanes with dihedral, and with wings swept back for stability. The era of refinement was about to begin. The value of streamlining was discovered, and higher flying speeds attained, the inefficient types of craft abandoned, and the way paved for progressive performance, reliability, and safety—the attributes of the airplanes of today.

CHAPTER II

Flight by Gas Bag

JUST as the beginnings of the airplane centered around the flight of birds, so did the balloon and airship evolve from the flight of clouds.

Men had long dreamed of balloons, as they had dreamed of flying machines, but up to the late eighteenth century, nothing practical had been done. As far back as 1650, Francesco de Lana described a flying boat with a sail, to be supported in the air by four large hollow copper balls from which all the air had been removed. In 1755, Joseph Galien proposed an airship supported by some form of lighter gas! There is no record that either of these men carried out their ideas, so the first practical experiments were not made until 1783.

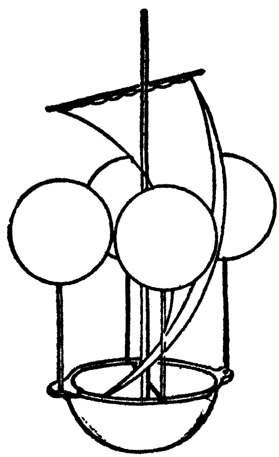


FIG. 6—De Lana's airship

It all began with the Montgolfiers, Joseph Michel and Jacques

Étienne. These brothers lived in the French village of Annonay, forty miles from Lyons. They had little scientific knowledge, but evidently they were of an inventive turn of mind. Watching the clouds floating in the sky, they began to wonder if it were not possible to fill a light envelope with "some substance of a cloud-like nature," and so make it rise in the air. The nearest convenient thing to a cloud was smoke, and this they decided to use.

Their father being a paper maker, they had no difficulty in procuring a number of large paper bags. Turning these bags so that the open mouths were down, they lighted fires of chopped straw under them. Hot air and smoke filled the bags, and when they were released they ascended. At the time, the Montgolfiers had no idea that it was the heated air that provided the buoyancy; they imagined that the smoke particles had the same quality of lightness as the water vapor particles of a cloud.

In spite of this misconception, their experiment was an unqualified success, and they hastened to repeat it on a much larger scale. This time, they used a linen bag 30 feet in diameter. On this occasion, the balloon quickly reached a height estimated at one mile, and flew for ten minutes before the air inside it cooled and allowed it to descend. This epochal flight came to the attention of the Academy of Science in Paris and created a great deal of interest. The inventors were immediately invited to repeat the demonstration at Versailles, on September 19, 1793. To this they readily agreed. They set about preparing an elaborate balloon of linen covered with decorated paper. A professor of natural history, hearing of this, raised funds for a more scientific experiment. The money was turned over to a noted physicist, J. A. C. Charles, who commissioned two brothers named Robert to make a silk balloon varnished with elastic gum. Charles knew that hydrogen, as well as hot air, was lighter than the atmospheric air, so he filled the balloon with that gas. This was the first hydrogen-filled balloon, and it behaved as its inventor expected it to, rising to 3,000 feet and traveling fifteen miles in three quarters of an hour.

But the Montgolfiers had not been robbed entirely of their day of glory. Before the King, the Court, and the leading citizens of

France, the fire balloon was prepared for its flight. Into a basket suspended from its open mouth were placed a sheep, a duck, and a cock—the first aerial passengers in history. One reason for including these animals was to learn whether or not the upper air was likely to have a bad effect on a human being—if a person daring enough could be found to make a future flight. After eight minutes,

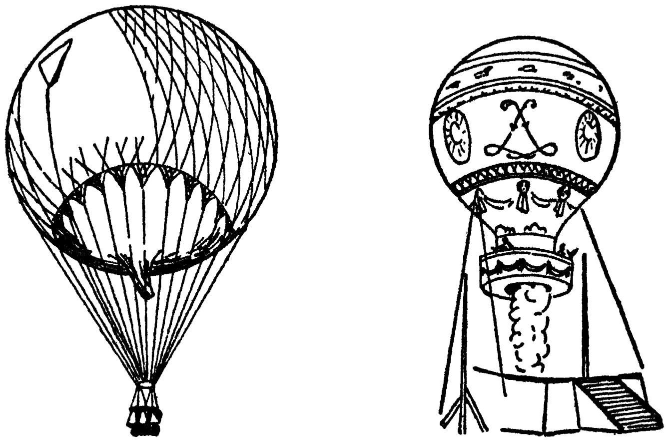


FIG. 7—Left: Modern free balloon; Right: Montgolfier's balloon

during which it ascended to 1,500 feet, the balloon came down again two miles away, its passengers were found to have suffered no ill effects, and plans were made for the first ascent of a human aeronaut. There was, however, no rush on the part of the populace to acquire this distinction. A judge suggested that a couple of condemned prisoners be given the chance, but a young gentleman named Jean François Pilâtre de Rozier objected. "The chance might succeed," he said. "The honor of being the first man to fly should not go to a convict but a gentleman of France!" And so, on October 15, 1783, de Rozier went up in a Montgolfier balloon. But this time, a rope was attached to the balloon so that it could not rise more than 100 feet, and it hovered there for four minutes before sinking slowly to earth.

De Rozier made other ascents, with a brazier of burning coals

mounted under the open mouth of the balloon to maintain the supply of hot air. Then, a month later, de Rozier and the Marquis d'Arlandes made an ascent from Paris, flying five miles in twenty-five minutes at an altitude of 3,000 feet.

It was obvious to the Montgolfiers that such short flights were of little practical value, and they set about finding means of prolonging them. The braziers of burning coals suspended from below the open necks of the balloons were far from satisfactory, and there was great risk of the balloon itself catching fire. Finally, they too adopted hydrogen in place of hot air, and long flights became possible.

In December, 1783, Professor Charles piloted an improved balloon made of rubber-coated silk. In this balloon he introduced features of modern balloons, such as a netting from which a car was suspended, and a valve in the top of the bag to permit the release of gas. It was 27 feet in diameter, and traveled twenty-seven miles in two hours at an altitude of 2,000 feet.

Simultaneously, in Philadelphia, other interesting and useful experiments were being made. Two members of the Philosophical Society, D. Rittenhouse and F. Hopkinson, attached forty-seven small hydrogen-filled balloons to a basket. After sending it to a moderate height at the end of a rope, with several small animals aboard, they looked around for a human passenger. A local carpenter, James Wilcox, was bribed into making the experiment. After ten minutes of free flight, with the balloon drifting toward the river, he became alarmed and brought the contrivance down by punching holes in some of the balloons. This was the first free flight in America.

Travel by balloon at once introduced new problems of control. It was soon discovered that there were air currents at different levels in the atmosphere. To make use of these, in order to go in the desired direction, the balloon would have to be controlled vertically. Bags of sand or water were carried to regulate the height to which the balloon would ascend. By dumping part or all of this ballast, additional altitude could be gained as required. To bring the balloon down to a new level, some of the gas could be released.

This arrangement was simple but not entirely practical, and during the next hundred years many devices were tried to provide steering and propulsion, to take the place of the winds.

In 1784, the French aeronaut, François Blanchard, first tried to propel his balloon with oars, and later with a hand-driven propeller. Neither scheme was notably successful. An interesting feature of Blanchard's balloon was an open parachute carried above the basket. Two other experimenters, Janinet and Miolan, tried hot-air jets (a forerunner of jet propulsion?); and a man named Bourgeois experimented with inclined planes with equal lack of success.

In this same year, however, an important contribution to the art of aerostation was made, all unwittingly, by another Frenchman, Meusnier. This man tried to provide altitude control by the use of an air cell or ballonet inside the balloon. The idea was to vary the balloon's displacement. But, since the buoyancy of the balloon was not affected by the filling or emptying of this ballonet, it did not produce the desired result. Many years later, Dupuy de Lome used this idea to maintain the gas pressure inside airships in order to preserve their shape and rigidity.

In 1842, two other experimenters, Monck Mason and Julien, built model airships propelled by clockworks, which were controllable. For this type of airship, designers, beginning with Sir George Cayley in 1816 and the Comte de Lennox in 1834, abandoned the spherical balloon and began to use cigar-shaped envelopes, pointed at each end so as to slide easily through the air.

One of the first aeronauts to use a steam engine was Henri Gifford, in 1852. He installed a 3 h.p. engine on an experimental airship, driving a two-bladed propeller which gave it a speed of 7 m.p.h. Steering was effected by a triangular piece of canvas at the rear.

As in the case of airplanes, the full development of steerable airships had to wait on the availability of light and powerful engines. The first airship in which such an engine was used was the revolutionary aluminum-hulled, rigid airship made by Schwarz in 1897. A close runner-up in the adoption of a gasoline engine was the

famed Santos-Dumont, who later turned to airplanes. His small airships were each driven by a gasoline engine which turned a two-bladed propeller in front of the pilot's seat. Ahead of him also was a horizontal hinged flat surface that served as an elevator. The rudder consisted of canvas stretched on a vertical hexagonal frame near the rear of the envelope. To steady the ship in flight, a large horizontal surface was mounted forward of the rudder. With such a machine Santos-Dumont flew, in calm weather, over Paris and around the Eiffel Tower.

But as Santos-Dumont and others discovered, the more slowly the airship moved, the more was it at the mercy of the winds and sudden gusts. For safe and comfortable flight, heavier and bigger and faster ships were required that could not so easily be blown off their course. To make them more practical, greater lift was needed in proportion to their size.

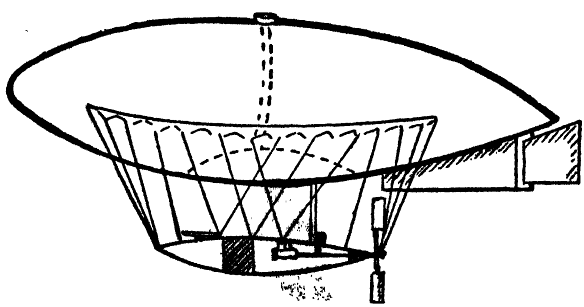


FIG. 8—Early type of airship

Typical of the first ships of this kind is the one shown in Fig. 8. This ship had a light but strong envelope of varnished fabric, kept stiff by the pressure of gas inside it. This pressure was maintained by the use of a ballonet. As the buoyant gas expanded and contracted with changes in altitude and temperature, the amount of air in the ballonet was adjusted accordingly. When the gas filled the envelope at its normal pressure, the ballonet was empty, but if the gas escaped, or shrank, due to increased air pressure outside, air was forced into the ballonet by a fan to take up the loss. In this

way, the outer skin was kept tightly stretched and in shape so that it offered the least resistance to the air.

The car on such a ship was made of light metal tubing or wood, and was suspended from the envelope by ropes. Inside it was the engine, driving a stern propeller, and space for the crew. Above the car was an elevator, and a rudder was mounted on a stabilizing fin attached to the underside of the envelope. This formed what is now known as a non-rigid type of airship.

Other types of airships were beginning to be developed at this time. The non-rigid were limited in size, because of the stiffness of the envelope required to support heavy loads. The larger ships were provided with a keel to stiffen them longitudinally, and the car was suspended from this. This kind of airship is called a semi-rigid type.

Most ships, from this time on (1870), now used hydrogen in place of coal gas, which many had used after 1836 because it was cheaper and more generally available. Hydrogen gave the greatest possible amount of lift in proportion to the volume of the envelope. Air weighs, at sea level pressure and normal temperature, about 81 pounds per 1,000 cubic feet. Coal gas, at the same temperature and pressure, weighs 35 to 45 pounds per 1,000 cubic feet. This means that the airship can only lift 46 to 36 pounds for each 1,000 cubic feet. Hydrogen, on the other hand, weighs only 5 pounds per 1,000 cubic feet, which will therefore lift 76 pounds. These are theoretical figures, and in practice may be some 10 to 12 per cent less in lifting power.

While Santos-Dumont and others were experimenting with comparatively small airships, much larger ships were being built. Two brothers named Tissandier had built an airship driven by an electric motor from batteries, and, in 1884, this airship attained a speed of 7 m.p.h. This performance attracted the attention of two French army officers, Captain A. C. Krebs and Captain Charles Renard. Obtaining a grant of $40,000 from the government, these men built a 66,000-cubic-foot airship, also electrically powered. The envelope was of fine silk, and the car of split bamboo.

On August 9, 1884, they made a circular flight of five miles with

this ship, at an average speed of 14.5 m.p.h. This was taken as conclusive evidence that the large airship was thoroughly practical. This conclusion was supported by the man who was even then in process of becoming the designer and builder of the largest airships ever made, Count Ferdinand von Zeppelin.

As early as 1871, Zeppelin had made drawings for a large airship with a rigid frame and several separate gas compartments. In 1891, he retired from the army to develop this type of ship. By 1894, he had completed detailed designs for a rigid airship which embodied practically all the essential features of modern craft of this type. The first of these ships was completed at Friedrichshafen in 1900. It was 420 feet long, 38 feet in diameter, and contained 388,410 cubic feet of gas. Its frame consisted of twenty-four longitudinal girders braced by sixteen transverse rings and diagonal wires. This was entirely covered with cotton fabric to give a smooth, streamlined shape. The gas was contained in cells made of rubberized balloon cloth. Below the ship was an external keel-like structure connecting two cars, in each of which was a 16-h.p. engine, driving a propeller on either side. On tests this ship attained a speed of 13.5 m.p.h. Compared with later airships, of 6,000,000 cubic feet and over, this was but a miniature model; yet it proved the theories of Zeppelin and prepared the way for the modern giants to come.

Despite the activities of Zeppelin and other builders of rigid airships, there was still plenty of interest in balloons and non-rigid airships, and in the semi-rigid, which were later developed. Even today, each finds its place and purpose in the conquest of the air.

Airships of Today

The spectacular advances in design and performance of the airplane during World War II have somewhat overshadowed the quiet but steady improvements made in airships. These improvements have been slow but revolutionary.

During World War I, for example, the non-rigid blimps had a gas capacity of 80,000 cubic feet and a speed of around forty-seven miles an hour. By the end of that war, the C class airships

of the U.S. Navy had attained a size of 200,000 cubic feet, and a speed of sixty miles per hour. Today's Navy K-ships contain no less than 416,000 cubic feet of gas and push through the air at eighty miles an hour!

In the early days, each ship carried three to five men, and fuel for one day's flight. Today, they carry eight or ten men on a 2,000-mile trip. The open cars of the first blimps have given way to closed cars streamlined into the bag, heated and noise-proofed. Accommodations now include navigation and radio rooms, sleeping quarters, and a photographic dark room. No longer does it take a large ground crew to handle the ship in taking off and landing. The old bumper bag that eased the shock in landing is gone. In its place is a caster wheel on which it can roll up to a mast, or skim along the ground to take off like an airplane.

Like seagoing surface vessels, these modern airships can undertake long voyages, and can be refueled and serviced en route. Like airplanes, they are aerodynamically clean—all the suspension cables for the cars are enclosed in the envelope.

During the war years, little has been done in the development of the large rigid airship, but many of the lessons learned from the non-rigid blimps, and even free balloons, can undoubtedly be applied to those rigids now on the designers' drawing boards. With the coming need for long-distance transport of passengers and goods, the rigid airship will have an important place in world-wide aerial transportation. Modern rigid airships of the Macon type, but larger, will be able to cruise at speeds of ninety to 110 miles an hour, carrying loads of 100 to 125 tons.

The largest rigid airship made thus far was the German Hindenburg, which had a gas capacity of 7,070,000 cubic feet. The biggest American ships were the Akron and Macon, with a capacity of 6,500,000 cubic feet. But airships are now projected which will owe their buoyancy to 10,000,000 cubic feet of gas. The reason for these big aerostats is the fact that lifting capacity increases in greater proportion than the size and air resistance. The biggest ship is the most economical because more of its lift can be devoted to paying load combined with higher speed. Other advantages

become evident when we look into the principles on which these lighter-than-air aircraft are designed and built.

The lift provided by a balloon or airship is static lift, as compared with the dynamic lift of airplanes. The balloon is supported in the air because it is lighter than the air around it—the same reason that a body floats in water. The balloon does not depend on motion for its support. As old Archimedes said over two thousand years ago: Any body immersed in a fluid is acted upon by an upward force exactly equal to the weight of the fluid displaced. All airships in the United States are filled with helium, which is thirteen and a half times lighter than air.

Hydrogen is fifteen times lighter than air, but the fact that it burns in air, and, under certain circumstances, may explode, makes it unsafe for use in airships and balloons. Since air weighs about 81 pounds per thousand cubic feet, and helium weighs less than 65 pounds, each thousand cubic feet of helium in an airship will give around 75 pounds lift. That is the theoretical figure. In practice, it is commonly assumed that 1,000 cubic feet of helium will lift 65 pounds, as against 70 pounds for hydrogen. One reason for this is that neither gas is 100 per cent pure.

On this basis, an airship of 10,000,000 cubic feet of helium should have a lift of 650,000 pounds, or 325 tons! About half of this lift is required to raise the structure of the airship itself, leaving a net payload capacity, for passengers and cargo, of 162 tons.

Of the three types of airships built—the non-rigid, semi-rigid, and rigid—the rigid is the best for heavy-duty, high-speed work. The building of the airship upon a rigid metal frame permits of maintaining a properly streamlined shape with large over-all size. Furthermore, power engines can be used because of the adequate distribution of the thrust stresses that the frame makes possible. The rigidity of the covering, due to adequate support of the skin, preserves the streamline form at high speeds, and is capable of withstanding the buffeting of gusts in stormy weather.

In the newest rigid airships everything but the forward part of the control car is enclosed within the skin. Even the engines are mounted inside, driving the propellers through extension shafts

and bevel gears. This, of course, would not be possible with a hydrogen-filled ship. The rigid airship frame is one of the most beautiful pieces of structural engineering ever conceived by the mind of man. The entire hull is built up of polygonal, girder-type frames of aluminum alloy. These transverse rings are spaced along the length of the frame, are tied together by longitudinal members, and are braced with diagonal wires.

FIG. 9—Rigid airship

The main transverse members are these ring-shaped girders, stiffened by cables called chord wires. Between each pair of these is an intermediate transverse ring (sometimes two) which has no bracing wires. The space between each pair of main transverses therefore forms a receptacle for a gas cell. An axial cable, extending from the bow to the stern, passes right through the gas cells, supporting them at their centers and tying the whole airship together. Over the whole assembly is stretched a stiff wire netting, and over that a cord netting which supports the outer covering fabric.

In a typical large rigid airship there are twenty-five or twenty-seven longitudinal girders, and about thirty-two transverse members accommodating twelve to seventeen separate gas cells. These cells are gas-proof fabric bags of cotton impregnated with gelatin-latex. Each of them is provided with an automatic valve to release gas in case of excessive pressure due to high altitude operation, and a manual valve for emergencies. Around each cell is a cordage net which holds it in shape to prevent it bulging or chafing against parts of the frame. The lift is transmitted through a wire netting outside this.

The engines, probably six or eight in number, are built into the side keels so that they can be serviced inside the airship and will not add to the wind resistance. The propellers are supported at a distance from the sides of the airship by means of streamline struts.

The main stiffening member of the frame is the keel. On large ships there are three of them, also of girder construction, and triangular in section. The base of each keel forms the support for a walkway, by means of which the crew can get from one end of the airship to the other. Part of the keel structure also forms quarters for the crew, and provides space for the fuel tanks and water ballast bags. Here will also be found the passengers' cabins and cargo holds.

The control car is always located at the forward end of the airship, projecting below the keel, outside of the skin. At the rear end the frame terminates in a pair of horizontal and a pair of vertical surfaces. These are the stabilizing fins, and attached to them are the rudders (upper and lower), and the elevators. In the upper part of the tail there might be an auxiliary control room, principally for use in maneuvering on the ground.

At the nose of the airship is a round metal plate, called the bow cap. One end of the axial cable is attached to it, inside the envelope, and it forms a base for the mooring cone by which the ship may be coupled to a mooring mast. In the center of this terminate the pipe lines, through which the ship is refueled and supplied with ballast water.

Each of the engines is probably 500 to 750 horsepower, and each is equipped with gears so that the propellers can be reversed. Instead of reversible engines, it is possible that reversible electric propellers would be eminently suitable. This reversing feature is of great value in maneuvering the craft and in checking its speed when mooring. Additional safety might be secured by adopting the Zeppelin idea of using Blau-gas as fuel in place of gasoline, or perhaps oil-fuel diesels. Better still would be the new jet-propulsion turbines which use kerosene.

An important control feature is the disposition of the ballast bags or tanks throughout the length of the ship. Water is carried for ballast, and in trimming the ship it can be pumped from one tank to another as required. Another reason for using water is that it can be added to in flight by condensing water from the exhaust gases of the engines. Without this water-recovery feature,

the airship would become constantly lighter as the engines consumed fuel and oil. It does not take many hours for an engine to use up its own weight of fuel, and if this weight is not counterbalanced in some way, the airship would become lighter and would rise. This would make it impossible to control the vertical movement of the airship without releasing precious helium, which might well be urgently needed before the voyage was done.

More water can be extracted from the exhaust gases than the weight of the fuel consumed. This is due to the large amount of oxygen taken from the atmosphere to mix with the hydrogen released by combustion.

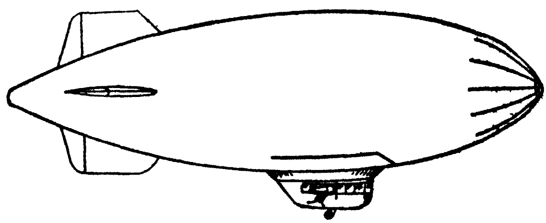


Fig. 10—Modern blimp

The non-rigid, blimp type of airship differs from the rigid type in many respects, but it also has its place and purpose in the aeronautical scheme of things. Non-rigids are small compared with the rigid type, the largest to date being 250 feet long as against the Hindenburg's 813 feet. It has a capacity of 416,000 cubic feet of gas.

Unlike the rigids, these limp bags have no internal stiffening structure. Their skins are formed so that they will assume a more or less streamline form when they are inflated. Stabilizing and control surfaces are fixed to the rear of the envelope. The car is attached to the underside of the envelope, and is supported by cables attached to the inside of the envelope at the top. The two engines used for propulsion are supported by streamlined struts on either side of the car.

At high altitudes, and when the envelope is heated by the sun, the gas in the envelope expands; at low altitudes, and when cooled,

it contracts. But the pressure inside the envelope must be main tained at the proper level to fill it out. This is necessary to preserve the shape of the envelope at low altitudes and to avoid the necessity of releasing gas at high altitudes. As mentioned earlier, this problem of maintaining a constant pressure inside the bag with a varying volume of gas is solved by the use of an internal ballonet. This ballonet is a space partitioned off from the gas-filled portion of the envelope by means of a fabric diaphragm. In effect, it forms a small air bag inside the gas bag. The ballonet is intended to be filled with air that is forced in under slight pressure to take up the space released by the contracting gas. Sometimes the movement of the ship through the air will force enough air into the ballonet through a scoop, but more often a blower is needed.

The small size of the blimps makes it impractical to use a water-recovery system, with its attendant weight, air resistance, and complication. As a rule, they do not need such a device because they can pick up water ballast as they need it. On long flights where extra ballast becomes necessary because of fuel consumption, the blimp can drop to within 100 or 150 feet of the ocean or other water surface, and can take aboard as much as is required.

The necessary apparatus consists of a hose with a bronze scoop on the lower end. About 25 feet from the scoop is a small electric pump enclosed in a streamlined casing, with a tail fin to keep it from spinning. This unit trails on the surface of the water, with the scoop behind it and slightly beneath the surface. The entire apparatus, which weighs a little over 100 pounds, can pick up ballast at cruising speed, regardless of whether the water is smooth or rough.

Another ingenious arrangement enables the blimp to pick up fuel from surface ships without either of them having to stop. All that the blimp pilot has to do—after making the proper arrangements with the ship's commander—is to drop two special fabric bags on the ship's deck. One of these bags is inflated with air so that it acts as a float. It is attached by a 14-foot rope to the other bag, which is larger and serves to hold the fuel. When the

fuel bag is filled, the whole thing is dumped overboard. Since both bags float, it is a simple matter for the blimp pilot to drop a hook between them and haul them aboard.

Another device which increases the usefulness of the blimp is a special sea anchor, which holds it stable even over a rough sea. With such equipment, the airship can remain close to a surface ship to take on or deliver supplies or transfer crews, or it can hover stationary while repairs are being made, or can serve as a marker for salvage crews hunting a wreck.

The anchor consists of a conical, waterproof fabric bag, about 10 feet long and 2½ feet in diameter at the upper, open end. The opening has a wire mesh cover, strong enough to support the weight of a man, but offering no resistance to water entering the cone. With the airship hovering 50 feet above the water, the bag is lowered on the end of a pair of cables which form a rope ladder. The lower halves of the cables are made of heavy elastic cord to absorb sudden shocks when the water or air is rough.

As the cone fills with water, the airship discharges ballast, raising it halfway out of the water. The sea anchor then becomes an automatic snubber. If the airship tends to rise, the load on the cables becomes increasingly heavy as the cone rises out of the water. If the ship sinks, the weight of the anchor is reduced as the cone is more and more submerged. When it is no longer needed, the cone is tipped and emptied by pulling on a cord attached to its apex. The whole thing can then be hauled aboard.

Each of these devices could be used just as well for the intermediate type of airship, the semi-rigid, and possibly by the rigid. The semi-rigid ship utilizes the principles of both rigid and non-rigid types. It relies mainly on gas pressure to keep the shape of its envelope, but it is stiffened by a girder-type keel that extends from one end to the other. In some instances, the nose is stiffened by a metal frame to preserve its streamline form against pressure at high speeds. A useful feature of the blimp is that it can easily be deflated and packed for transportation when necessary. The semi-rigid can also be packed for shipment, although the keel offers a problem of stowage.

Current semi-rigid airships are 300 feet in length, or over, with gas capacities up to 719,000 cubic feet. Their maximum speed is around sixty miles an hour. No recent ships of this type have been constructed, and very little attention has been given them in the United States. Usually, the keel is articulated so that excessive rigidity of the bottom of the bag will not cause damage under stress. The keel is triangular in section, enclosed within the envelope, the gas space being formed to accommodate it.

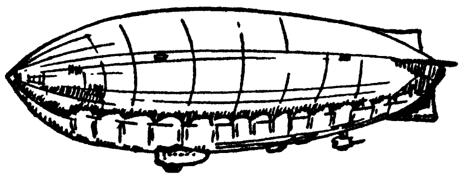


FIG. 11—Semi-rigid airship

The use of helium in all of these ships has practically eliminated the hazards of fire. On the other hand, the gas cells and envelopes are all of combustible material. The search for a more fireproof type of structure led to the investigation of all-metal airships. One of these, the Metalclad, ZMC-2, was built for the U.S. Navy, and has given excellent results for reasons other than safety. This type of airship is made entirely of thin aluminum plating attached to a light frame of the same metal. This plating is air-tight, and it acts as a cover, a gas container, and supports the load.

The whole structure is lighter than a fabric-covered ship of the same size because there is no necessity for a heavy framework, or for separate gas cells and netting. The only fabric used is a ballonet diaphragm. This is required because it is necessary to maintain gas pressure, since the covering cannot adapt itself to changes in volume as a fabric bag or cell can.

Its light weight gives the Metalclad a proportionately higher load-carrying capacity. The ZMC-2 measures 153 feet long by 53 feet in diameter, and with a skin that is only 0.009 inch thick, weighs 8,800 pounds. It can transport a load of 4,800 pounds at seventy miles per hour, with a total of only 400 horsepower to turn

its two propellers. Whether or not such a ship can be constructed in a size large enough to transport 100 tons of cargo, however, still remains to be seen.

The operation and control of all types of lighter-than-air aircraft is an art in itself. Because the airship is statically buoyant, it needs no horsepower to lift it. Its engines can be far smaller than those needed for airplanes because their sole function is to propel the ship through the air. They do not have to lift it as well!

This is not to say that dynamic lift does not have its place in airship operation. It does. In taking off in a blimp, for example, the fuel load, and therefore the range, can be substantially increased by the proper use of dynamic lift. The horizontal fins and rudders, together with its broad undersurface, give the airship this lift. The blimp pilot starting on a long trip will fill his tanks with all the fuel the airship can statically lift. Then he may add another ton of fuel. By taxying across the landing field he can attain sufficient speed to acquire the necessary dynamic lift to overcome this excess weight. Even in rigid airships, this principle is often applied to gain extra altitude in emergencies.

Excess buoyancy can also be attained by what is known as super-heating. Any gas expands when warmed. Expanding in an airship envelope it displaces more air and therefore gives added lift. When an airship is exposed to the sun, the gas becomes warmer and expands. This allows the ship to get off the ground with an added load. This excess buoyancy, due to superheat, may well last until enough fuel has been used to reduce the load to normal.

One of the major problems connected with large airships has been the handling of them on the ground. Formerly, it was necessary to provide hangars in which the ships were kept between trips. But moving them in and out of the sheds was fraught with difficulty and danger. Nowadays, this is not necessary because such ships can quite safely be moored in the open, except under extreme weather conditions. The early hangars gave way to high mooring towers which, in turn, were displaced by stub masts which hold the ship close to the ground. The hangars are replaced by airship docks which are used principally for construction and overhaul.

Normally, the ship will be moored to a low mobile or fixed mast, like a surface ship at anchor. Such masts terminate in a steel cup mounted on a radial bearing. On the nose of the airship is a hinged steel cone, with its main mooring cable passing through its center. A similar cable extending through the mast cup is led down inside the mast to a winch.

In mooring the ship, the ship's cable is attached to the mast cable, and the cone pulled into the cup. The cone spindle is carried in a tube so that the airship is free to roll as well as to move sideways. Other lines from the nose of the ship are attached to winches on the ground to keep it from yawing in the wind. The biggest problem is to keep the ship from moving up and down, and no system so far devised is one hundred per cent satisfactory. But that problem, too, will undoubtedly be solved as more large airships are built and begin to take their rightful place in the coming world-wide system of international air transportation.

CHAPTER III

The Mechanics of Flight

WITH engines and propellers roaring, the sleek airliner skims along the runway. Faster and faster it goes, its broad wings outstretched to catch the rushing wind. Smoothly the great ship eases itself into the air in a gentle climb. The ground drops away beneath it, and the landing wheels fold slowly under the air-borne wings. Higher and higher it climbs as it swings onto its course, and soon it is but a speck on the horizon.

To anyone watching that great silver airplane mount into the sky, the whole process may seem as easy and natural as a bird taking flight. Yet here is a metal monster weighing many tons. Inside it are twenty-four people and a great deal of baggage, and there is no firm foundation for it to ride upon—nothing to support it but air! How, then, can an airplane fly? How can the air, which has so little substance, be made to support so great a weight? To find the answer to that riddle, it is necessary to know what happens when such solid objects move through the air.

From what was said in Chapter I regarding the origins of the airplane, it should be obvious that an airplane is supported in the air through the reaction between its wing and the air through which it moves. To understand airplane flight it is only necessary to know what that reaction is. What actually happens is that an airplane goes up because it pushes the air down. Unfortunately, the process by which it does this is not so simple as the bald statement might suggest.

To anyone who has ever flown a kite, it should not be difficult to realize that the kite stays aloft because of the wind pressing against it. The string holds the kite at the proper angle so that the pressure of the air on the front of it lifts the kite and does not simply push it backward. The kite is, of course, very light, and it does not

take much wind to support it. If there is no wind blowing, the kite can be made to go up, and stay up, by pulling it along through the air.

The airplane wing is very much like a kite because it, too, will stay up if it is held at the proper angle to the wind. The wing, being heavy, naturally needs a much stronger wind than the kite does, which means that the air has to move at high speed past it. Furthermore, since the wing would not be of much use if it stayed in one place, it is made to move through the air, and by this movement it creates its own wind as it travels.

Both the kite surface and the wing are airfoils, which means that they are surfaces designed to secure reaction from air moving past them. But compared with the wing, the kite is a very inefficient airfoil because only one surface works to make it rise in the air, i.e., to give it lift. The wing is an improvement on the kite because both sides of it are put to work. An airplane made on the principle of a kite would be impractical because the amount of power necessary to keep it moving through the air would be so great that there would be no reserve for carrying either a pilot or passengers. A great deal of that power would be employed, not in creating lift, but in pulling the kite-plane through the air. That power would be wasted in merely overcoming the resistance of the kite to the forward motion.

The resistance of any airfoil to motion through the air is called drag, and an airplane wing has to be made of such a shape and thickness that just pulling it through the air will give it a lot of lift without very much drag. In this respect, the difference between a wing and a kite is all-important. In the first place, all the lift that the kite gets comes from the pressure of the wind on its under surface. The upper surface does nothing but interfere with the movement of the air that passes over it—and that interference causes drag. In other words, it pulls the kite back in the direction of the wind, but it does not help to lift it.

If it were possible to see the air rushing past a kite (this can be done in a smoke tunnel), it would look somewhat as in the drawing, Fig. 12, Left. In this view, the air is shown pushing against

the under surface of the kite. That flow of air is deflected by the kite, but it is still smooth and unbroken. At the top of the kite, however, the wind rushes over the edge, leaving a patch of comparatively still air next to the surface. The moving air, whirling around this pocket of still air, breaks up the smooth flow, producing whirls and eddies. This break in the smooth flow retards

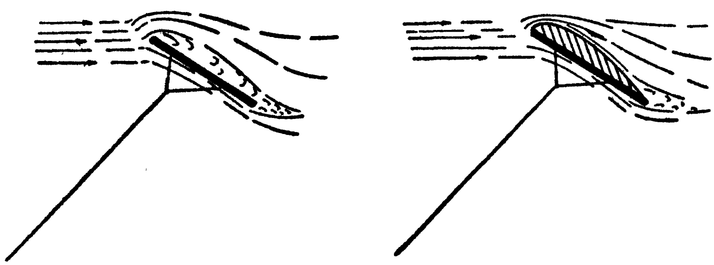


FIG. 12—Left: Air flow past kite—excessive burble area at back produces much drag; Right: Kite drag reduced by filling in burble area

the flow of the adjacent layers of air in the air stream. The result is that the air stream tends to pull the surface in the direction in which the wind is moving. That is why the upper surface of the kite contributes almost nothing but drag—and that would make it useless as an airplane wing.

In order to do away with the drag caused by the turbulent air, some way would have to be found to eliminate the pocket of dead air so that the air flow over the surface will be smooth and unbroken. The most obvious way of doing this would be to fill in that space with something solid. The result would be that the kite would have a curved upper surface, somewhat as shown in Fig. 12, Right. Air flowing over this surface then follows the contour, and its flow is uninterrupted. The result is that the main cause of the drag is done away with.

Now, while the elimination of this drag is quite an achievement, something just as important has happened in connection with the lift. With the plain kite surface, all of the lift came from the up-

ward pressure of the air on the underside. With this new, curved surface, about three quarters of the lift is supplied by the upper side. In other words, the lift has been multiplied by four! The reason for this is that while the pressure of the air on the under surface is increased by the deflection of the air stream, the pressure of the air passing over the top of the wing is decreased even more. It is this difference between the air pressure under the wing and the air pressure on top of it that creates the total lift provided by each square foot of the wing surface.

This is simple enough to understand. It is only when we try to figure out why the air pressure over the wing drops so much that we need some knowledge of aerodynamic principles, as well as imagination. The generally accepted aerodynamic principle on which the theory of wing lift is based is called the Bernoulli law, or theorem. This law tells us that whenever the speed of a gas such as air is increased, its pressure is decreased.

In Fig. 13, this is shown by a diagram of what is known as a venturi tube, which is a tube having a narrow portion, or throat,

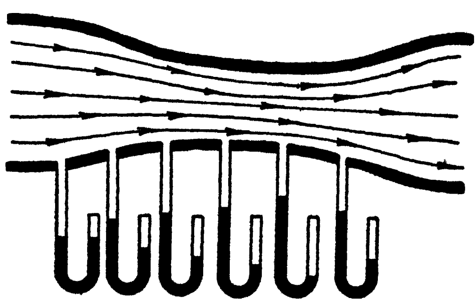


FIG. 13—Venturi with manometers to show pressure variation

in the middle. Air flowing through this tube travels at a certain speed. This speed is the same at both ends of the tube, both inlet and outlet being of the same diameter. At the center part of the tube, where the bore is smaller, the speed of the air is increased, just as the velocity of water flowing out of a hose pipe increases when the end of the hose is squeezed.

This increase of velocity takes place gradually as the diameter of the bore is reduced, and decreases again as the bore widens toward the exit end. The pressure of the air inside the tube becomes less as the speed increases, and greater as the speed is reduced. This is very easily shown by connecting pressure gauges or manometers at various points along the venturi, as shown in Fig. 13.

The manometers are U-shaped glass tubes, with one short and one long leg. The longer leg is connected to the venturi so that its open end is exposed to the air stream. The elbow of the U is partially filled with a colored liquid so that the height of the liquid in either leg can clearly be seen. The short leg of the tube is open to the atmosphere; therefore, any reduction in pressure inside the venturi will cause the liquid to move up the longer leg. The higher the liquid in the long leg, the less the pressure in the venturi. A typical example of the pressure variations appears in Fig. 13, mentioned before.

By careful design of the restricted portion of the venturi tube, the maximum pressure reduction can be secured at any required

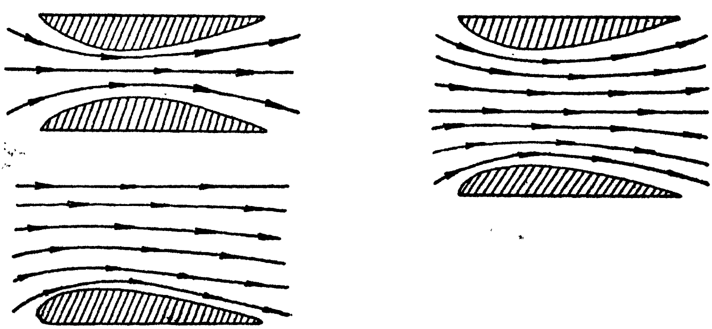


Fig. 14—Development of wing section from venturi; Upper left: Normal venturi; Upper right: Wider wall separation does not change effect; Lower left: Removal of one wall still works

point. Usually, the tube is so designed that the throat is reduced rather sharply at the entrance, and gradually widens again toward the exit. This gives a sharp reduction in pressure at the narrowest

portion of the throat, the pressure reduction getting less and less toward the outer end of the tube.

This same effect is secured whether the tube is narrow or wide, and it is a curious fact that one half of the tube will work in the same way as the whole tube. If the tube is cut in two lengthwise, or if the tube is opened out flat, air flowing over the bump formed by the restriction will be speeded up and its pressure on the surface reduced. This is the principle which is applied to the airplane by substituting a wing for the venturi.

If a wing is cut through from front to back, it will be found that it is practically the same shape as the flattened-out venturi. And

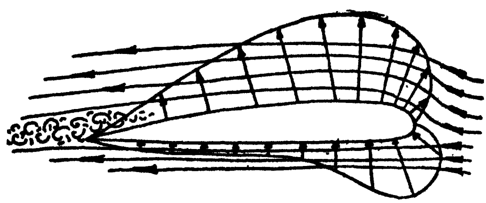


FIG. 15—Pressure distribution on a wing at normal angle of attack

it works in the same manner because air flowing over its upper surface has its pressure reduced by its automatic increase in speed. This curve of the upper surface of the wing is called its camber, and it is usually highest near the nose, or leading edge of the wing; it is there that the greatest amount of lift is generated.

There is, of course, much more to the wing than this. Unlike the venturi, the whole wing is exposed to the flow of air (the air stream). As the airplane moves through the air, the wind rushes across the under surface of the wing as well as over its upper surface. If the underside of the wing is perfectly in line with the air stream, nothing will happen except that the air pressure below the wing will not change noticeably, but that above the wing will be reduced. On the other hand, if the wing is tilted a little so that the lower surface slopes up into the air stream, the air will not be able to glide under it in a straight line. It will be pushed down by the wing, which means that the air will be pushing the wing

up just as strongly—otherwise there would be no pressure between them.

Two things, therefore, are happening to the wing: it is being pushed up by the moving air beneath it, and its upward lift is being assisted by the low pressure of the air above it. These combined forces—the increased pressure below and the decreased pressure above—produce the lift that is required.

These pressure differences ~~do not have~~ to be very great to be useful. Take a wing 20 feet long and 5 feet wide (technically, 20-foot span, 5-foot chord). This would give 100 square feet of wing area. If the air pressure above the wing is decreased by three quarters of an ounce per square inch, and increased by one quarter of an ounce per square inch under the wing, the difference in pressures will be 1 ounce for each square inch of wing area. On the 100 square feet of total area—14,400 square inches—the total lift will be 900 pounds! If this lift force is greater than the weight of the plane, the plane will rise. If the lift is equal to the weight, the plane will remain at whatever level it is at the moment.

The amount of lift that a wing will produce depends upon a number of things, such as its total area, its thickness and degree of camber, its proportion of length to width, its plan shape, and its angle of attack (the angle at which it meets the air stream).

The length of a wing, measured from tip to tip, is the span. The width, measured in a straight line from the nose to the trailing edge, is the chord. The proportion of span to chord is called the wing's aspect ratio. Generally, a wing with a high aspect ratio (a long, narrow wing) is more efficient than one with a low aspect ratio. One reason for this is that some of the high-pressure air below each outer end of the wing escapes around the wing tip into the low-pressure area above the tip. This produces a whirling air current, or vortex, which adds its resistance to the air stream. Such resistance is a form of drag, and, with a narrow wing, this effect is reduced. Some improvement is made by tapering the wing, but the taper must not be made too great or the wing may tend to stall abruptly at the tips. What this means will be seen when stalling is explained.

The amount of lift a wing will give at any specified air speed depends largely on the shape of its section—that is, from back to front. Some wing sections give twenty-four times more lift than drag. This ratio is governed to a great extent by the curvature (camber) of the mean line of the wing section. When this camber is high, as in the case of the thick wings used on some transport planes, the lift is great at comparatively low speeds. Low-cambered, thin wings have little drag, but require a high air speed to provide the lift. They are, therefore, suitable for high-speed planes.

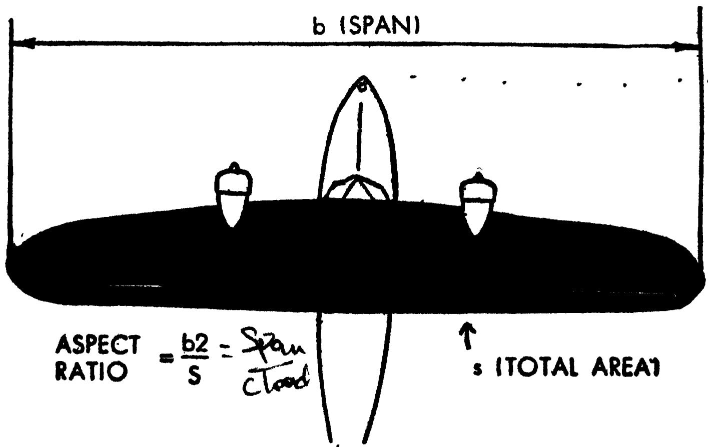


FIG. 16—Aspect ratio

If the underside of the wing is concave, the weight-carrying power may be increased at the expense of speed, and convex undersides give added speed with a little loss of lift. Securing a wing section that will produce the best results on any given airplane is therefore one of the major problems that designers have to face.

An important factor in the operation of the wing is the angle at which it meets the air stream. This angle is called the angle of attack. To get the greatest amount of lift, the air must be allowed to flow smoothly over the upper surface of the wing, for reasons already explained. That flow must not be interrupted or broken,

and the layer of air in contact with the surface must not be allowed to leave it. Tilting the wing, up to a certain point, will give increased lift. When the position is reached at which the maximum lift is attained, any further increase of the angle will destroy the lift and cause the airplane to fall. The point at which this occurs is called the stalling point.

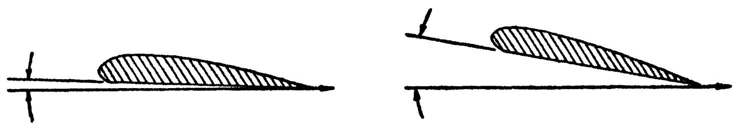


FIG. 17—Angle of attack; Left: low; Right: high

The loss of lift in a stall is caused by the air stream breaking away from the upper surface, so that instead of a smooth flow, eddies or burbles are formed, extending forward from the trailing edge. This action and its causes may be better understood by a brief study of streamlining in general—another important factor in reducing drag on an airplane in flight.

Airfoils are surfaces designed to secure reaction from air moving over them. Streamlined surfaces are designed to eliminate all pos-

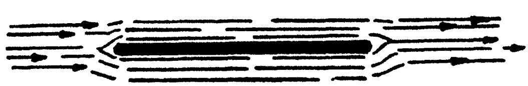


FIG. 18—Air stream passing over flat plate, low drag

sible interference with an air stream. If a flat plate is exposed, edge-on, to an air stream, as in Fig. 18, the stream will be very little disturbed. It will flow fairly evenly around the plate, and any drag will be caused by the friction of the air moving over the surfaces. But if this plate is turned so that it faces the air stream, quite different conditions exist.

The air striking the front of the plate, in effect, piles up against it. It presses against the surface, and the high pressure at the point of contact pushes it outward toward the edges of the plate. The air that escapes over the edges has its velocity considerably in-

creased because of this initial pressure. All around it, air at normal pressure tends to push it back into its original stream direction.

The result of both the speed and the pressure is the formation of a low-pressure area behind the plate. The fast-moving, low-pressure air tends to suck out the remaining air, while the low pressure draws air from the passing stream. The result is a confusion of eddies behind the plate, reduced pressure, and therefore induced drag.

As in the case of the kite, previously discussed, this formation of eddies behind the plate produces most of the drag, and much of it is due to the increase of air speed past the edges. That speeding-up

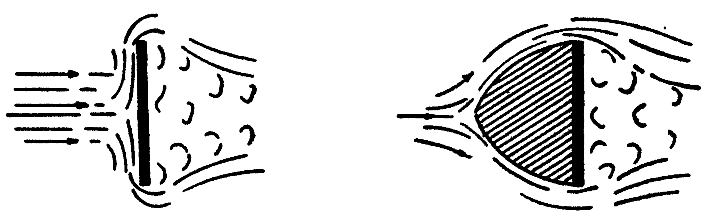


Fig. 19—Left: Pressure and turbulence created by flat plate at right angles to air stream; Right: Elimination of front pressure on plate still leaves large turbulence drag at rear

effect can be reduced by cutting down the air pressure on the front of the plate, and the simplest way to do this is to fill up the space that would be occupied by the compressed air. If this space is filled by a solid object, the shape of that object might well be something like half an egg, as in Fig. 19, Right. What happens now is that the air stream is smoothly divided as it strikes this fairing, and there is no sudden increase in pressure. The air then slides smoothly past the edges of the plate with very little increase in speed, and the eddying behind the plate is reduced. At the same time, the pressure on the front of the plate is practically eliminated.

Since it is the eddying that causes most of the drag, the drag can more effectively be reduced by fairing the back of the plate also. This fairing will follow the outer limits of the space in which the eddies take place, extending backward to a point at which the

divided air flow normally comes together again. This fairing will not be the same shape as that in front of the plate, but will taper off for a considerable distance, as in Fig. 20.

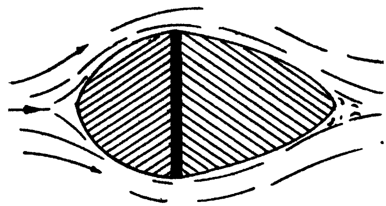


FIG. 20—Filling in of rear turbulent area provides streamline flow

The two sections of fairing, with the plate sandwiched in between, now constitute a streamlined body, their surfaces representing a line along which a stream of air will flow, with the greatest ease, past an object as large as the greatest diameter of the fairing. A fairing four times as long as that diameter is a good working average.

In the case of a wing, the designer's aim is to secure the maximum of lift with a minimum of drag. The plain streamlined shape would provide the low drag, but it would give no lift unless it were tilted. The next best thing is to proportion the wing so that the air stream maintains smooth and even contact with its surface from front to back. If the wing camber is arranged to give the desired lift, the rest of the upper surface of the wing will follow the natural flow of the air, and the air will remain in contact with the surface as far back as the trailing edge. The wing will then have no drag, except that due to skin friction—a condition that can never be achieved in practice.

With a well-designed wing, the angle at which it meets the air stream can vary over a wide range without undue loss of lift. But there is always a point past which this angle (the angle of attack) cannot be increased. When that point is reached, the air layer breaks away from the surface, just as it did behind the plate, burbles are formed, lift is lost, drag is increased tremendously, and the airplane stalls and begins to fall. Devices employed to

increase the range of speeds and angles of attack at which the wing will continue to give adequate lift are described in Chapter V.

Reducing Airplane Drag

Because air moving over a surface rubs against it and produces friction, drag cannot be eliminated from an aircraft, however well streamlined it may be. But with good designs which are "aerodynamically clean," with polished surfaces, sunken rivets, retracted landing gear, and no projections to break the streamline form, most of the drag may be due to skin friction. This is called parasite drag, to distinguish it from drag due to other causes. This means that almost perfect streamlining has been achieved, and that the formation of eddies and burbles has been eliminated.

The principal single source of drag may be due to the wing itself. On all airplanes there are a number of other surfaces or airfoils, the purpose of which is to balance the wing in flight and control its direction. These also are described in detail in Chapter V. The complete airplane also requires some means of moving it through the air. The commonest arrangement at present is an engine and propeller, though the use of jet propulsion will no doubt be widely extended in the future. These power plants are described in Chapters VI and VII. The wing, the control surfaces, and the power plant, assembled to a body (called the fuselage) constitute the complete airplane. Naturally, all of the surfaces of the airplane are acted upon by the air in flight, and the resulting forces have to be estimated in developing the design.

When an airplane is in flight, there are four principal forces acting upon it. There is the force of gravity—its weight—trying to pull it to the ground; there is the pull of the propeller (or push of the jet), called the thrust; there is the lift of the wing, which keeps the plane up in the air; and there is the resistance of the airplane itself to its movement through the air, which is called drag.

The first of these forces, gravity, changes in flight, due to the consumption of fuel. Otherwise it is constant and acts in a vertical direction on every part of the ship. There is, however, one point

in the structure at which the weights of the parts balance one another. That point is called the center of gravity. In studying the forces acting on the airplane, the effects of gravity are taken to be concentrated at that point. Ordinarily, the center of gravity would be on or above the horizontal centerline of the airplane, and near to the leading edge of the wing.

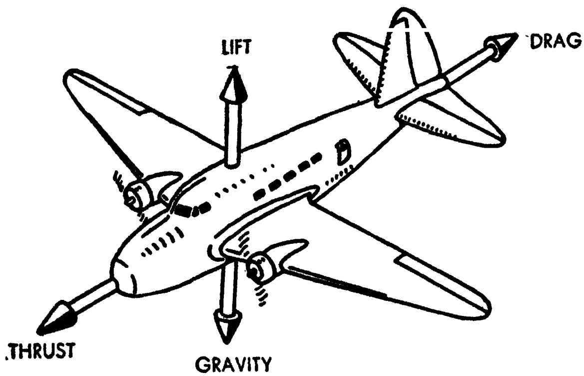


FIG. 21—The four principal forces acting on an airplane in flight

The force which we call lift acts approximately vertically in a direction opposed to the force of gravity. The pressures on the wing are many and varying. It is customary to group them at one focal point, called the center of pressure of the wing. This center of pressure is not fixed, but moves backward or forward in accordance with the changing angle of attack of the wing. Increasing the angle of attack moves the center of pressure forward. Normally, the center of pressure will vary in location from one fifth to one third of the wing chord length from the leading edge of the wing. Its position with relation to the center of gravity has a great deal to do with the stability of the plane in flight, as will be seen later.

The airplane is pulled or pushed through the air. This pull, or thrust, acts along the centerline of the jet or propeller shaft. This may be above or below the center of gravity, and it is not affected by the angle of attack. In aircraft with more than one engine, the thrust is considered as taking effect along the plane of symmetry

(a vertical plane passing longitudinally through the center of the fuselage) at a level in line with the centers of the propeller shafts or jet orifices.

Drag is the total of all the forces resisting the passage of the airplane through the air. This drag force is considered as being

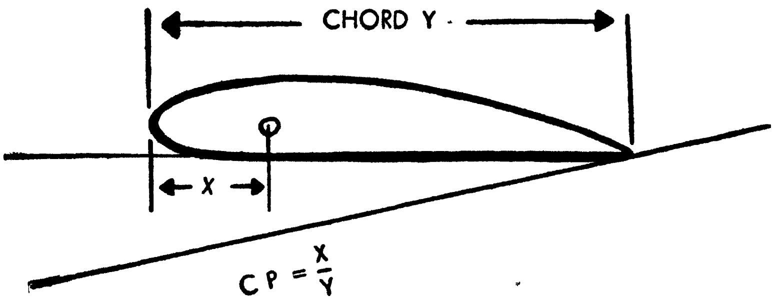


FIG. 22—Center of pressure coefficient

concentrated along one line, taking effect horizontally and backward, above or below the center of gravity. Since the proportion of wing drag to parasitic drag changes with the angle of attack, the location of the drag line also will change. Drag changes as the square of the velocity of the plane and is equal to the thrust, except during acceleration.

AIRPLANE STABILITY

If an airplane is properly designed, it will have the characteristic of inherent stability. This means that it will have a tendency to keep itself in a normal level flying position. If the airplane is in a climb or a dive and the controls are released, the plane will automatically level off and keep a straight course. It will tend to correct itself against changes of attitude due to sudden air currents that might make it swerve or roll or change its course. That is why, under ordinary conditions, such a ship can be flown "hands-off."

This characteristic of stability is extremely important to the pilot. Without it, flying in gusty weather would be extremely difficult and hazardous, if not impossible. With an unstable plane, if the

nose of the ship is put down by moving the control stick forward a little, the nose will keep on going down at an increasingly steep angle until the plane is in a dive. Such movement, therefore, would have to be constantly controlled. With a stable plane, the nose of the ship would only remain down until the control was released, when it would level off again.

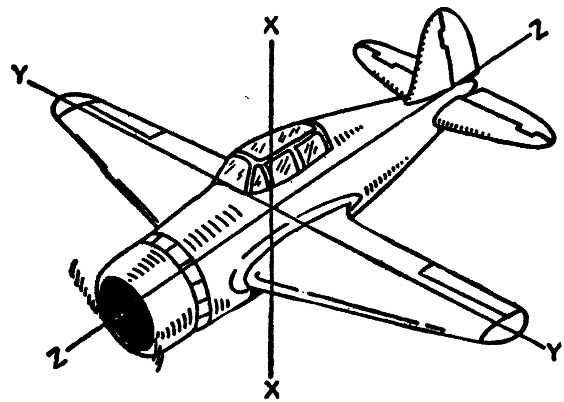


Fig. 23—The axes of an airplane: x—vertical; y—lateral; z—longitudinal

Since an airplane in flight is moved around three axes, it must be stable in each of these directions. Longitudinal stability refers to the movement of the plane around the lateral or transverse axis. In other words, it concerns the up and down movement of the tail in relation to the nose. The stability in this direction is determined by a number of things in addition to the general design. These include: (a) the longitudinal position of the center of gravity, (b) the vertical location of the gravity, (c) the amount of travel of the center of pressure, (d) the level of the line of thrust in relation to the centers of gravity and pressure, and (e) the design and setting of the horizontal tail members.

The longitudinal position of the center of gravity and its relation to the wing center of pressure is probably the most important factor. The loss of weight, and resultant change in weight distribution

due to burning of the fuel, as well as the placing of the cargo, affect the center of gravity, and may upset the stability under certain conditions. However, if the center of gravity remains slightly ahead of the wing center of pressure, the ship will be nose-heavy, and this can be counterbalanced by the setting of the horizontal stabilizer.

Such a balance would be for only one angle of attack and speed. If the elevators were not moved or the stabilizer adjusted, the plane would go into a dive when the speed was reduced. This dive would increase the speed of the plane, which would thereupon level off again into its normal attitude without assistance from the pilot.

Lateral stability governs the behavior of the plane with regard to its longitudinal axis. A laterally stable plane, given a rolling motion or thrown into a bank (tilted), will tend to right itself so that its lateral axis is again horizontal. In itself, lateral stability is rather less important than longitudinal stability. However, in certain rolling motions and sideslips, the action of the controls may not be effective and something more is needed to insure safety in flight. Any air disturbance that causes one wing of the airplane to drop may produce a sideslip. Some means is therefore required to check the rolling action of the plane and to restore it to its level position.

The commonest method of checking the rolling tendency is by setting the two halves of the wing at an angle to one another,

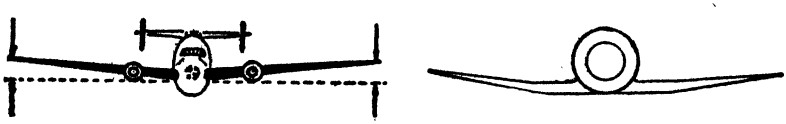


FIG. 24—Dihedral; Left: from fuselage; Right: from flat section

vertically. This angle is called dihedral. It is the acute angle which each half of the wing forms with the horizontal, or any line perpendicular to the ship's plane of symmetry. Tilting the wings toward the tips in this manner changes their respective attitudes to the air stream in a sideslip.

The sideslip, which is partly yaw (turning about the vertical axis) because of the simultaneous forward motion of the plane, causes the air stream to strike the wing at an angle. If the wing halves were in line with one another at their leading edge, the air pressure would be evenly distributed over them, and there would be no force tending to restore the plane to an even keel. With dihedral, however, the low side of the wing will have a greater angle of attack than the high one. This increases the lift on the lower wing panel, forcing it up and once more restoring the balance.

Sweepback, which is secured by setting the leading edges of the two halves of a wing at an angle to one another horizontally, also improves lateral stability. It does it in much the same manner as dihedral. It is not nearly so effective, but it is not so much affected by changes in air speed, and is more efficient near the stalling point.

Another factor in lateral stability is what is known as the keel effect of the plane. This is due to the area of surface that the fuselage and vertical tail members offer to the air in a sideslip. The more of this surface there is above the center of gravity, the greater will be the pressure tending to right the airplane. For this reason, some airplanes have very large fins, or fins extending along the top of the fuselage, which are called dorsal fins. This applies especially to seaplanes, the floats of which represent a large surface below the center of gravity, and to large, highly streamlined fuselages. Some weathercock stability is necessary in all airplanes; that is, they all need more keel surface at the rear than at the front.

Directional stability refers to the movement of the plane to right or left of a straight course. If it is stable on this vertical axis, it will counteract any sudden temporary force that swerves it from its course. The fin and rudder have considerable bearing on the directional stability because of their location well behind the vertical axis of the plane. They cannot be made disproportionately large because of the extra drag they introduce, and the overdamping of rudder movement that results.

Sweepback will contribute to the correcting of yaw. As the

plane swings off its course, one wing panel moves backward as the other moves forward. The air speed over the wing moving forward is increased, adding to the drag. The opposite effect takes place on the other wing panel so that the tendency is for both of them to resume their original positions.

More effective than sweepback in correcting yaw is the keel effect. If the areas of the fuselage and tail surfaces are so proportioned that the center of lateral pressure is close behind the center of gravity, adequate lateral stability will be attained. If the center of pressure is ahead of the center of gravity, or too far to the rear, the plane will be hard to control because directional stability will be reduced. Like the weathercock, the plane should naturally line itself up into the wind.

CHAPTER IV

Flying Machines and Windmills

An airplane is an aircraft, but not every aircraft is an airplane. A balloon, for example, is an aircraft, and so is a helicopter, but neither of these is an airplane. The balloon, the helicopter, and the airplane are, as a matter of fact, three distinct types of aircraft. These are distinctions necessary to bear clearly in mind in order that you may be able to differentiate between the kinds of aircraft and the flight principles on which they are based.

The two basic categories into which aircraft are divided are: (a) those that are lighter than air, like balloons and airships, and (b) those that are heavier than air, such as airplanes, helicopters, and autogiros. These heavier-than-air classes are subdivided according to their method of obtaining support in the air. All airplanes have "fixed" wings—that is, a wing or wings which are rigidly attached to the rest of the airplane. The other kinds have movable, or rotating wings or airfoils. Both kinds are driven by some mechanical means, generally an internal-combustion engine.

An airplane, therefore, is a mechanically propelled, fixed-wing, heavier-than-air aircraft. A helicopter and an autogiro are mechanically propelled, rotary-wing, heavier-than-air aircraft. Within this broad definition, airplanes are made in many types and sizes, all the way from giant 100-passenger sky liners to single-place light planes. Apart from size, or application, one useful way of differentiating between the various types of planes is according to the number and arrangement of the wings.

A monoplane has one wing, a biplane has two, one above the other, a triplane has three wings, also arranged vertically. Some variations of these also have special names. For instance, a biplane with one wing more than twice the size of the other is called a sesquiplane; an airplane with two wings, one behind the other,

is called a tandem airplane (not to be confused with a tandem-seated plane which has two seats, one behind the other). An airplane with more than three wings in a stack is referred to as a multiplane, but no such plane exists at the present time.

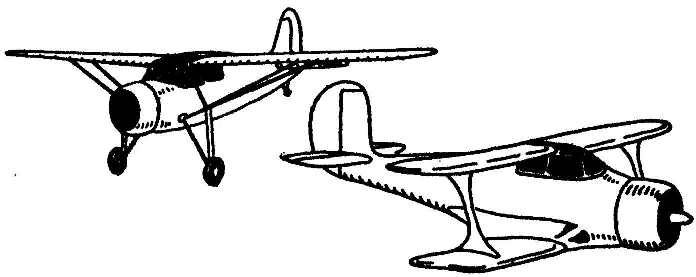


FIG. 25—Left: Monoplane; Right: Biplane

All of these types, and many others, have been built and flown in the early days of aviation, including one known as a canard (French for duck) type which has its main wing at the rear. This

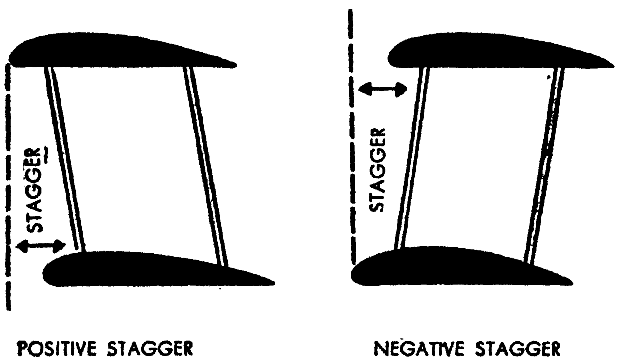


FIG. 26—Wing stagger

arrangement has a number of features to recommend it, and two such aircraft are among the latest of modern types.

Most modern airplanes have only one wing, though a number of important designs have two. The general idea behind the biplane

is that the double wing gives a large total supporting surface with a comparatively small wing spread or span. Furthermore, the wings can be braced together to form a stiff and rigid structure. The drawback to this is that the connecting struts introduce additional air resistance, or drag. To improve visibility for the pilot, or for more technical reasons, it is common practice to make one wing of a biplane larger than the other, or to place it in a slightly different position. If one wing is wider than the other, the difference is called overhang (positive if the upper wing is the longer, negative if it is the lower). If the leading edge of one wing is slightly ahead of the other, the wings are said to be staggered. If the leading edge of the upper wing is ahead of the leading edge of the lower wing, the stagger is positive. If the reverse is the case, the stagger is negative.

Another way of distinguishing between airplanes is according to the kind of surface they are constructed to take off from or alight upon. Those airplanes that are designed to operate from a solid surface, for instance, are termed land planes. Their landing gear may consist of wheels, for alighting on a prepared runway; a tractor-type track for landing on soft ground, or skis for alighting on snow or ice.

Airplanes made to alight upon or take off from a water surface may be of one or two types. One type has a fuselage similar to a land plane, but in place of wheels there is a float (or floats). This is called a seaplane. Many land planes can be converted to seaplanes by installing floats in place of the main wheels, but for work over salt water special precautions have to be taken to prevent corrosion of the metal parts. Specially built seaplanes, with one central float instead of two side by side, are used by the Navy for launching by catapult from the deck of a ship. In this case, a small auxiliary float is attached to each end of the wing to keep the tips out of the water and to preserve the balance.

The other kind of seagoing airplane has a boat-type body which supports it on the water. The body, or fuselage, is then in the form of a hull, and the airplane is known as a flying boat. The hull of the flying boat represents a compromise between a regular boat

hull and an airplane fuselage. It not only has to carry inside it the crew, passengers, and cargo, but must withstand the shock of landing (often in rough water), remain watertight, and be easy to move over the surface of the water as well as through the air. To offer a minimum of drag while in flight, it must be properly streamlined, yet its underside must be shaped so as to present an

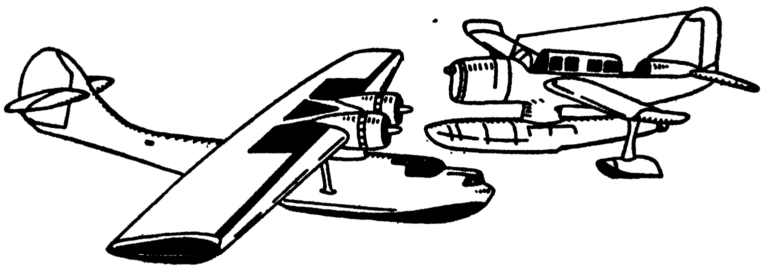


FIG. 27—Left: Flying boat; Right: Single-float seaplane

adequate amount of surface to the water so that it will not float too deep for an easy take-off.

When a flying boat takes off from the water it must break away from the surface easily, and that is not the simplest matter to arrange. It takes a great deal of power to separate the solid and the liquid surfaces, and this is aided by forming a step in the hull bottom. Then, when the hull is moving rapidly over the water, the break allows a film of air to slide between the water and the hull, from the step rearward. From this action comes the phrase, "riding the step"—which means that the ship is traveling fast, high out of the water, with only the step submerged, and may become air-borne at any instant.

Another important feature of flying-boat design is the location of the engines high above the water so that neither they nor the propellers will be struck by flying spray. All flying boats, therefore, have their wing or wings well above the water level. In monoplane types the wing is generally above the hull, either with the engines built into it, or mounted on struts above it. In some instances, extra clearance is secured by tilting the inner ends of the wing panels

upward from the hull. The wing is then shaped like the wings of a gull, for which reason it is called a gull wing.

Airplanes that are designed to operate either from land or water at will are called amphibians. These may be either the single-float seaplane type, or the flying boat type, or a twin-float seaplane may be fitted with what are known as amphibian floats. In all cases, the floats or hulls are equipped with landing wheels which (except

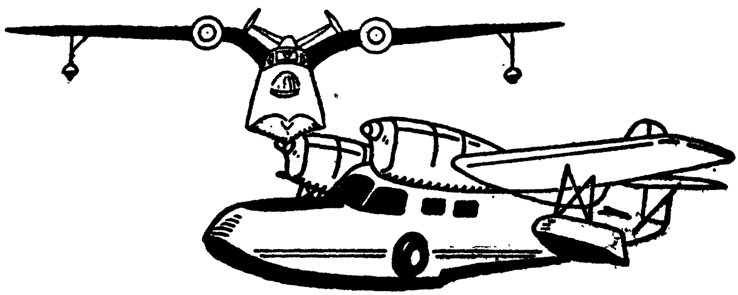


FIG. 28—Above: Flying boat with gull wing; Below: Amphibian

in the case of the twin-float amphibian) can be extended or retracted as required. When not in use, the wheels are withdrawn into the hull or float so that they do not add to the drag during flight.

Both of the present-day rotating wing types of aircraft—the helicopter and autogiro—may, theoretically, have any type of fuselage and landing gear. Up to the present, however, the autogiro has only been equipped with landing wheels. The helicopter, on the other hand, has made use both of wheels and special types of twin rubber floats, called pontoons. These pontoons allow the craft to alight on any surface, but, obviously, they do not serve all the purposes of wheels. This, actually, is of little importance because a helicopter can just as easily fly a foot or two above the ground as taxi in the conventional manner of airplanes. The autogiro, on the other hand, can conveniently use wheels because it can move about on the ground, being pulled along by a propeller, as in the case of most airplanes.

This method of propulsion is the distinguishing difference between the helicopter and the autogiro. Both aircraft are supported in the air by revolving airfoils or vanes—two, three, or four vanes forming a rotor. The rotor, in each case, is something like a giant propeller, but each blade (or vane) is hinged to the supporting shafts. The difference, in principle, between the two craft lies in

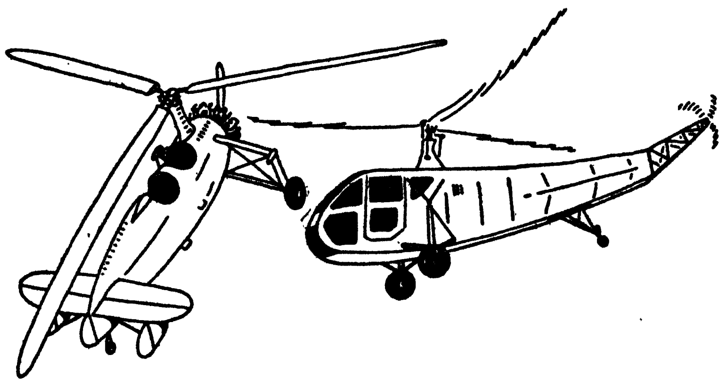


Fig. 29—Left: Autogiro; Right: Helicopter

the fact that the helicopter rotor is constantly driven by an engine (except when gliding), but the rotor of the autogiro revolves automatically when once the machine is in flight.

In the helicopter the rotor not only lifts the machine, but drives it forward, backward, or sideways. The rotor of the autogiro, on the other hand, merely provides the lift, and a separate means of propulsion (such as a propeller) must be provided to move it forward through the air. This is the reason that the helicopter can stand still in the air (hover), and move vertically up or down, or fly forward, sideways or backward, while the autogiro can only fly in one direction.

It is true that the autogiro can make a steep take-off (called a jump take-off), but there still must be some forward motion or the rotor will cease to revolve and the craft will rapidly descend. The helicopter needs no separate means of propulsion to move it

horizontally through the air because the rotor can be made to serve that purpose. Primarily, the rotor lifts the machine, but if the rotor is tilted forward, or backward, or to one side, some of its force will be expended in pulling the craft in that direction. A similar result can be secured by changing the angle of the rotor blades as they revolve. By regulating the blade pitch in this manner, and the speed at which the rotor revolves, the helicopter can be made to climb or descend as it moves along. It therefore requires no control surfaces, such as elevator, or rudder, or ailerons, to help it move in any direction.

Actually, some helicopters which have a single rotor also have a small vertical propeller at the tail, which can be used to turn the craft in any horizontal direction. The primary purpose of that propeller, however, is to counteract the tendency of the fuselage to revolve in the opposite direction to the rotor. Speeding up this propeller will turn the craft in the same direction as that in which the rotor is turning. Slowing down the propeller will let the fuselage swing around in the opposite direction. Since the rotor of an autogiro rotates automatically in flight, there is no force acting to turn the fuselage, and so no control propeller is needed. This is more fully discussed under the heading of propulsion systems. It is sufficient here to point out that the control requirements of the helicopter and autogiro are entirely different from those of the airplane, and this constitutes another point of difference between the two types of aircraft.

So far, autogiros have been made with but one rotor, and there is only one successful craft of this type in commercial production at this time. There is, therefore, no sub-classification of these craft. Among the helicopters, however, there is a variety of readily distinguishable types. Some helicopters have one rotor, and some means of counteracting the rotor torque reaction. Others have two rotors, mounted one above the other, rotating in opposite directions. This is the contra-rotating, coaxial type. Another design has two rotors side by side, rotating in opposite directions—the transverse twin-rotor type; still another, the tandem-rotor type, has one rotor at the front and one at the rear. It is the number

and placement of the rotors which constitutes the principal difference between the various designs of the helicopters, and forms a distinguishing mark between the types.

Airplanes of the monoplane type, beside being classified according to the number of their principal supporting surfaces (in this case, one), are also distinguished by the placement of their wing

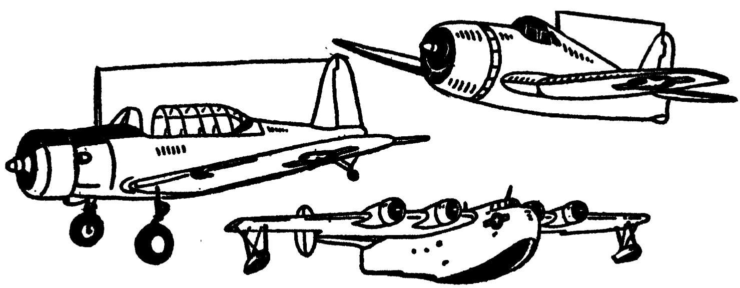


FIG. 30—Left: Low-wing monoplane; Right: Mid-wing monoplane; Below: High-wing monoplane

in relation to the fuselage. If, for example, the wing is attached to the fuselage at the bottom, the craft will be called a low-wing monoplane. If the wing is attached halfway between the top and bottom of the fuselage, it will be a mid-wing monoplane. When the wing is attached to the top of the fuselage, it is a high-wing craft, and if the wing is supported above the fuselage (by cabane struts), it will be a parasol type.

Each of these wing arrangements has something in its favor for the particular purpose for which the plane was designed. Such things as stability and visibility are taken into account by the designers, but often the arrangement is a matter of compromise. Parasol wings are often met with on light planes because they give excellent visibility of the ground beneath, the center of pressure is well above the center of gravity, so that extra stability in flight is secured, and the wing is high off the ground so that it is not so likely to be injured during faulty landing or ground looping. A low wing, on the other hand, gives better visibility all around,

as well as upward; it provides stiffer construction because the fuselage frame forms the wing center section, and it also provides both a convenient support and housing for the landing wheels. With this low wing, the landing wheels can be widely spaced so that there is little danger of one wing tip striking the ground in an awkward landing. Then, too, the low wing is considered by many to give the plane a more sporting and smarter appearance. Sometimes the inner wing panels are sloped down from the fuselage and the outer panels given appreciable dihedral, forming what is known as an inverted gull wing. The value of this type of wing is that the downward-sloping part makes possible a short landing gear, yet the fuselage is kept high enough from the ground to permit ample clearance between the propeller and the ground.

A prominent distinguishing feature of all airplanes is the number of engines used. When a single power plant is installed, this is usually located in the nose of the central fuselage. Airplanes in which the single power plant is mounted to one side of the fuselage are known as unsymmetrical planes. When two engines are used, it is customary to mount one on each side of the central fuselage, by attaching them to the wing. With three engines, one will generally be in the nose of the fuselage, with one on either side. The principle in the case of all multi-engined planes is to balance the power plants on either side of the fuselage. In some instances, this is done by attaching all engines to the leading edge of the wing. In other instances, two engines may be coupled in tandem (one behind the other), driving either two separate propellers or one pair of coaxial propellers.

Regardless of the number of engines used, the propellers may be either ahead of or behind the airplane wing. If they are in front of it, so that they pull the wing through the air, the plane will be known as a tractor type. If the propellers are to the rear of the wing, so that they push the wing forward, the craft is a pusher type. The tractor arrangement is generally more simple to design than the pusher, but the pusher has the advantage in that it causes less disturbance of the airflow over the wing, and a generally smooth airflow is essential to maximum lift. Where jet propulsion is used,

there is, of course, no interference with airflow at all, and the jet or jets always discharge to the rear. As in the case of engine-propeller combinations, there are multiple and single jet installations, arranged to produce equalized thrust on either side of the fuselage, if not along its central, vertical plane (called its plane of symmetry).

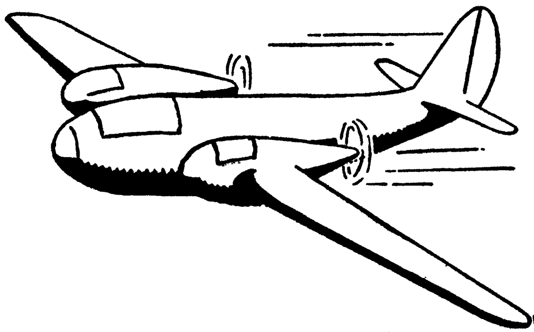


FIG. 31—Pusher-type airplane

CHAPTER V

The Anatomy of the Airplane

LIGHTNESS combined with strength is the first essential in any airplane. This means that the strength must be built in, but only where it is needed. In early types of airplanes parts were made light—often of wood—and given strength by being braced externally with

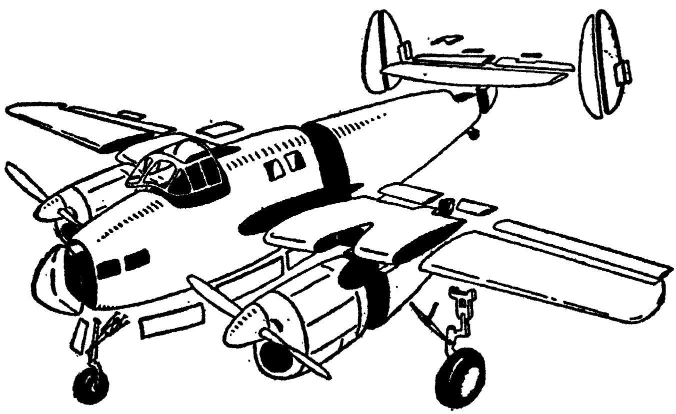


FIG. 32—Assembly units of a twin-engine, twin-tail, midwing monoplane with tricycle landing gear

rods and wires. In modern high-speed aircraft it is necessary to make the exterior of the plane aerodynamically clean. That is to say, if it is at all possible to avoid it, there must be nothing exposed that will interfere with the free flow of air. With the development of strong and light metal alloys, this has become a much simpler problem for the designer, and external bracing, such as struts and wires, is little used except on the smallest planes. The problem there is not so acute, since these planes fly at comparatively low speeds.

To determine where strength is required the designer has to analyze the stresses to which the plane will be subjected, and the forces that the airplane structure will be called upon to resist.

Each working surface of the airplane—the wing, the ailerons, the rudder, and the elevators—is an airfoil, designed to obtain reaction from the air through which it moves. These reactions mean that some force is being exerted, and where such forces exist there is stress. Stress may be defined as the resistance any surface or body offers to any force that tries to change its shape or form, and should not be confused with strain, which is that which happens when the stress becomes too great and the object is deformed.

In flight the airplane is constantly subjected to a great variety of stresses in many directions at once. Air in motion is pressing on the surfaces with different degrees of intensity, pushing them one way, then the other, with all the force of a wind blowing at a hundred or more miles an hour. Changes of direction and the operation of the control surfaces apply pressure in one direction to some parts, in another direction to others. Gusts may lift the tail and not the wing; other air currents may twist the tail, or lift one side of the wing and not the other.

The reaction of the engine driving the propeller is constantly trying to turn the plane over in the other direction. The propeller is actually a moving airfoil, as will be shown later. In acting on the air, it sets up a resistance to turning. This resistance reacts on the engine, so that the engine itself tends to turn in the opposite direction to the propeller. This reaction is resisted by the airplane itself. That resistance constitutes another force acting on the airplane structure, in addition to the forward pull of the propeller.

The varying pressures of air on the body, wing, and control surfaces are continually trying to move the metal skin or fabric covering in relation to the framework underneath. The airplane is, in fact, acted upon in all directions, and it must be built to resist these manifold stresses. This does not mean that every part must be perfectly rigid. On the contrary, a little elastic "give" is necessary in most parts to accommodate sudden excessive stresses without permanent deformation.

The five forces to which the parts of the airplane are subjected are: (a) torsion (twisting), (b) tension (stretching), (c) shear (cutting), and (d) bending (a combination of stretching and compressing, with a shear stress along the plane between them). These things should be kept in mind in considering the purpose and construction of each major part of the plane.

The simplest type of airplane is the light land plane, one of which is illustrated in Fig. 33, page 65. This particular plane weighs 720 pounds, and it will carry a load of 530 pounds through the sky at better than a hundred miles an hour, although its engine is rated at only 65 h.p.—less than many an automobile engine! In the little cabin, which can be seen directly under the wing, two people can be seated in comfort, and there is room for a reasonable amount of baggage.

On this type of airplane the cabin is sound-proofed so that the pilot and passenger can talk in normal tones. Though they cannot be seen in the picture (Fig. 33), there are, on the instrument panel, dials that tell how fast the plane is traveling through the air, how high in the air it is, how fast the engine is turning over, and its oil pressure and temperature. It is controlled by a wheel. Altogether, therefore, it is much the same thing as an automobile, except that it rides on air instead of concrete, and in place of wheels it has a wing.

To enable it to take off from, or alight on, a land surface, this airplane has a pair of main landing wheels at the forward end, and a small caster wheel under the tail. As it has a single wing which is attached to the top of the body, it is called a high-wing monoplane. The fuselage is streamlined to reduce wind resistance, and terminates in a tail assembly or empennage. This tail unit consists of a vertical fin to which the rudder is attached, and a pair of horizontal surfaces, called stabilizers, which support the horizontal movable surfaces, known as elevators.

The units marked on the illustration are the essential parts of any land plane, whether it be a light "flivver" plane or a sky liner. The design and construction of these parts vary with the type and make of airplane, but their purposes remain the same.

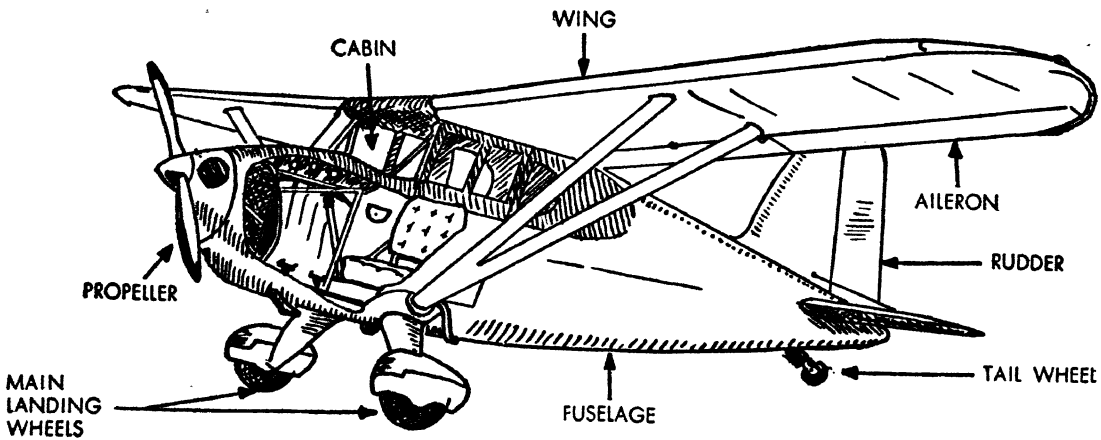


FIG. 33—Parts of an airplane: a light monoplane with cabin cut away to show controls and engine support

In Fig. 34, page 67, the principal parts of a military airplane are shown. Starting at the front of the airplane, there is, first, the propeller, which has three blades. Immediately behind it, enclosed within a metal cowling, is the engine. In the light plane (Fig. 33) this engine was a small, air-cooled unit. In the case of the pursuit plane, it is a twelve-cylinder, liquid-cooled engine, with a radiator for the cooling fluid underneath it. The engine is supported by brackets attached to a transverse metal bulkhead, called a firewall. The purpose of this firewall is to prevent fire or gasoline fumes from spreading to the cockpit where the pilot sits. Behind this firewall is the instrument panel.

In the cockpit, which can be enclosed by a sliding cover, are the controls, and a seat for the pilot. Behind the seat is the main gasoline tank, an oil tank, and another transverse bulkhead. All along the body, between the firewall and the tail assembly, are a number of curved ribs which support the body skin. These also are called bulkheads or former rings. The lengthwise pieces are longerons or stringers. Inside the tail is the tail wheel, which has been drawn up inside the skin. Above it are the control cables for the rudder and elevators. As its name suggests, the vertical stabilizer (also called the fin) helps to keep the craft steady by preventing the tail from swaying sideways. The rudder, which is hinged to the fin, steers the craft to left or right (like the rudder of a boat)—that is, to port or starboard.

The horizontal stabilizers steady the tail in a vertical direction, and at the same time form the supports for the elevators. The elevators are, in effect, a horizontal rudder. When they are swung down, the tail goes up and the nose of the plane goes down. When they are turned up, the nose of the plane is pointed upward. The fin, rudder, stabilizers, elevators, and the structure that holds them together form the tail assembly or empennage.

Turning now to the view of the wing, Fig. 34 reveals the internal construction. Since it supports not only itself but the entire airplane in the air, it is very strongly constructed. This particular wing is made wholly of metal. The center part of the wing, called the center section, is built into the body of the airplane.

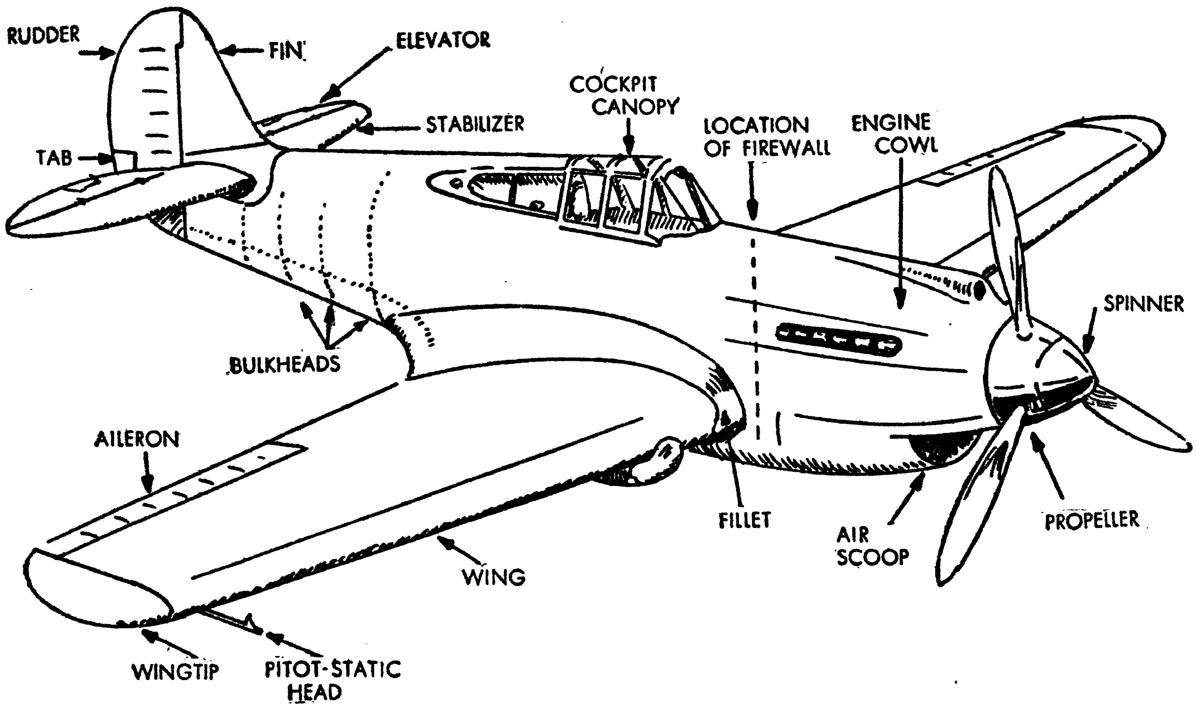


FIG. 34—Parts of a military airplane

Each outer section or panel is built around two deep, longitudinal members, called beams or spars, which extend to the wing tips. These are the main supporting members, and on other planes

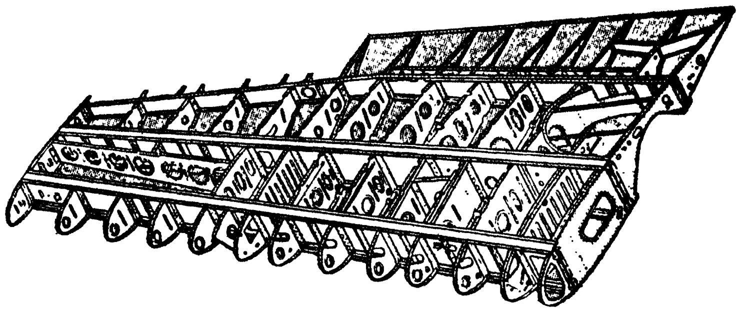


FIG. 35—Structure of an all-metal wing

there may be two, or three, or only one. Attached to them are other members, running fore-and-aft, called ribs. Some of these are used simply to preserve the contour of the wing surface, and they are then called former ribs. The main or compression ribs are attached to the spars to form girder-like structural units. In the small planes, many of which use wooden ribs, the internal bracing

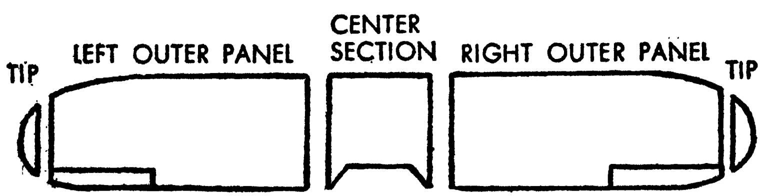


FIG. 36—Units of a wing

of the wing consists of taut diagonal wires. Those wires that resist the backward pull of the wing tips are called drag wires; those that work in the reverse direction are anti-drag wires.

In the military plane illustrated, the wing is covered with a metal skin which is stretched on so that it stiffens the whole structure and takes some of the load. This skin is supported by longitudinal, corrugated sheet metal sections, part of which show

in the drawing. Also shown is a retracted landing wheel, and one of the wing machine guns. The wing tip is fitted as a separate piece.

Built into each end of the wing is a long rectangular section extending to the tip. These sections are the ailerons. Like the elevators in the tail, they are hinged so that the back or trailing edge

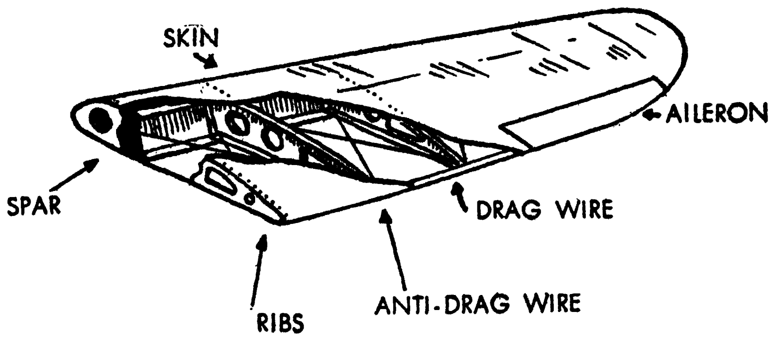


FIG. 37—Interior construction of a wing with drag bracing

can be moved up and down. These two ailerons are so connected to the controls that when one turns down, the other turns up. In flight, this causes one half of the wing to rise and the other to fall, tilting the plane on its longitudinal axis. That movement is called rolling if it is used during straight flight, and banking if it is applied in a turn. Banking is necessary in making turns to prevent skidding.

These, then, are the principal parts of the airplane: the wing or lifting surface; the engine and propeller, which provide the necessary thrust to move the wing through the air; the control surfaces, through which the direction and position (the attitude) of the airplane can be changed, and the body or fuselage, which provides space for the pilot, passengers, and load, and holds the other parts together; and, finally, the undercarriage and gear, which permit the plane to take off and alight safely and with little shock.

Types of Fuselages

The largest unit of the airplane structure is usually the fuselage. The function of this fuselage is to contain the crew and cargo (persons or goods), support the flying and control surfaces, and sometimes the engine and landing gear. All of the loads imposed by these things are therefore transmitted through the body structure in some way, and it must be built to withstand them.

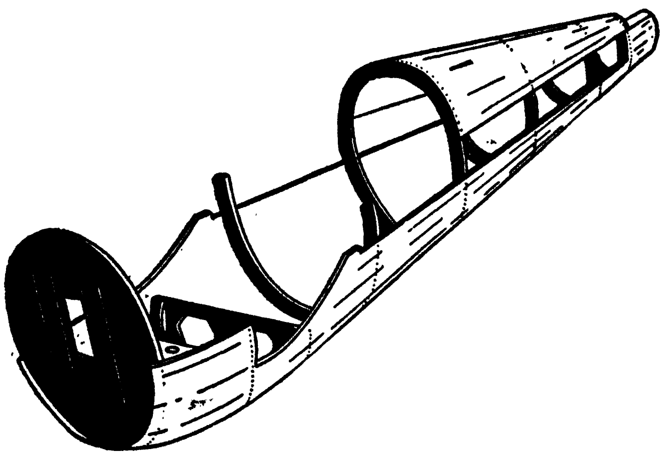


FIG. 38—Monocoque fuselage construction

There are three general types of body construction in use at the present time. For small planes, particularly the fabric-covered ones, the truss-type body frame is used. The truss frame is usually constructed of welded steel tubing. This tubing is arranged so that the individual tubes are either in tension or compression. This is because tubes can better withstand these longitudinal forces than they can bending stresses. They are formed into a more-or-less rigid framework, called a truss. Sometimes the tube structure is reinforced by means of diagonal tension wires or rods.

The two other common types of bodies are for metal-covered fuselages. They are the monocoque and semi-monocoque types.

In both of them the metal skin is made to carry part of the load.

One of the strongest of engineering forms is the tube. A metal tube will withstand greater bending loads than will a solid bar of the same diameter, provided the wall thickness is properly proportioned. The tube also has superior torsional (twisting) strength. In non-technical language, this is due to the fact that the stresses are transmitted through the tube walls around the circumference, instead of short-cutting through a solid center. In other words, the tube acts as a built-up girder instead of as a bar or plain beam. Within certain limits, a tube of large diameter with a thin wall is generally stronger than a tube of smaller diameter with a thicker wall.

The monocoque (mono=one; coque=shell) construction adapts the principle of the tube to the fuselage. While the necessarily thin walls of a fuselage would withstand many of the stresses imposed in flight, concentrated loads of certain kinds would produce a wrinkling of the metal. To avoid this by distributing the loads more evenly throughout the skin, the structure is stiffened internally. This is done by inserting stiffening rings at intervals along the length of the fuselage. These rings are called formers or bulkheads, and the metal skin is riveted to them.

To obtain the maximum strength in all directions, it is a common practice to further stiffen the monocoque fuselage by means of longitudinal ribs or stringers. These stringers relieve the skin between the bulkheads of a great deal of compressive and torsional stress. This results in a stiffer and stronger body, and constitutes what is known as a modified or semi-monocoque construction. In this type of body the skin is riveted to both the bulkheads and the stringers. This semi-monocoque arrangement is used on the majority of metal-skinned fuselages, including those of the large transport planes of the air lines.

A further modification of the monocoque principle is what is known as a reinforced shell. In this type of fuselage the stressed skin is supported by a framework composed of ribs, with longerons spaced around them or arranged in a spiral form. In place of ribs, the framework may be composed of a basketwork or lattice ar-

rangement of spiral members. This is sometimes referred to as a geodetic construction.

Wing Construction

The main supporting surface of the orthodox type of airplane is the wing. The wing extends outward from each side of the fuselage, and must therefore be strongly constructed to withstand the enormous leverage involved in supporting that weight in flight. It must also be firmly attached to the fuselage so that its own weight will not deform it through the impact of landing. This means that the wing must be rigidly supported vertically, and, in addition, must be designed to resist inertia stresses in a fore-and-aft direction due to starting and stopping, and the pressure and rearward drag of the air in flight.

Furthermore, since the wing is an airfoil of special section, it must be constructed so as to preserve that cross-sectional shape

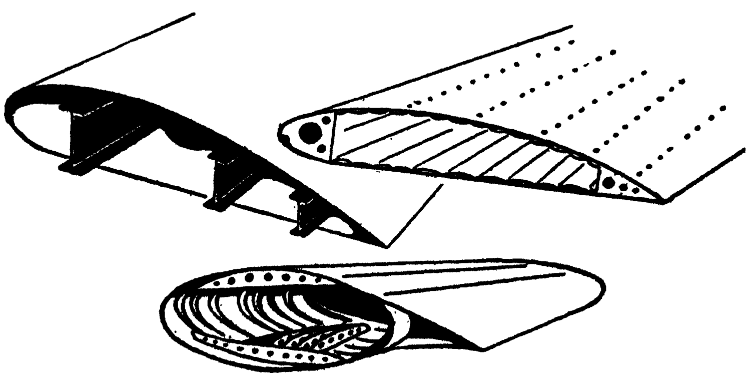


Fig. 39—Left: Multispar wing; Right: Shell wing; Below: Monocoque wing

under all normal, and some exceptional, conditions. The two main supports of the wing, then, are the longitudinal (the long way of the wing), and the transverse (fore-and-aft, in this case) structures. The longitudinal structure consists of one or more beams, called

spars. The transverse units, which follow the sectional contour of the wing, are called ribs.

On early airplanes the wings were made wholly of wood, braced internally with wires, and externally with wires or struts, and covered with fabric. Planes of current design may have (a) wood spars, wood ribs, wood or fabric skin, (b) wood spars, metal ribs, wood or fabric skin, (c) metal spars, metal ribs, fabric or metal skin.

On all modern fighting ships, the whole wing structure is of metal. But on some large transport airplanes, such as the Douglas DC-3's and some smaller ones, the skin is metal except for the control surfaces, which are fabric-covered. This reduces weight, lightens control operation, and somewhat simplifies servicing. The metal skin covering the wing proper usually forms parts of the structure, as in a semi-monocoque-type fuselage. This makes possible a very strong and rigid wing so that no exterior bracing is required on even the largest planes. Wings which are not externally braced, but are supported only at their junction with the fuselage, are known as cantilever wings.

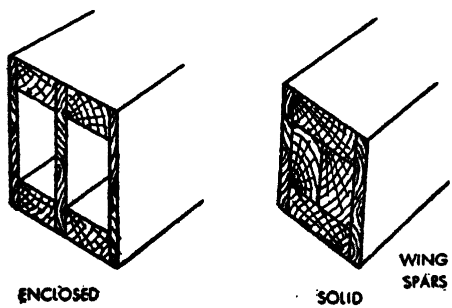


FIG. 40—Wing spars of wood

Not so long ago, all spars were made of wood. Today, wooden ones are used only on some light planes. Such spars may be made from a solid wood beam (plain or laminated), in the form of a box, or I-shaped in section. Sometimes they are built up into the form of a girder, just as is a metal spar.

In order to get sufficient strength in a limited space, it is necessary to use metal spars for large airplanes. Wood spars would be too bulky, and probably too heavy. With metal spars and ribs it is possible to apply a stressed skin that will form an extremely strong wing structure, and this is general practice on all large airplanes. The metal spars may be of any section, the commonest being the I-beam. A monospar-type wing beam usually is made in the form of a wide box spar, though tubular single spars also have been used.

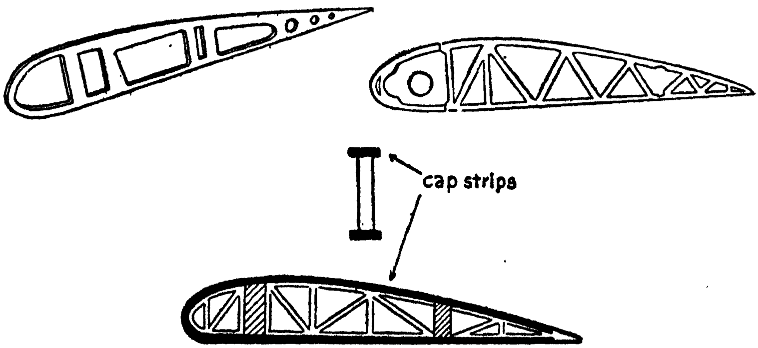


FIG. 41—Left: Wing rib of punched web type; Right: Punched truss type; Below: Capstrip on wood rib

Aircraft wing ribs are constructed in a variety of ways—all of them based on the same principles as the spar design. They may be of the web, box, or truss type. Some of them are used to tie the spars together, and, by taking a compressive stress, form an important part of a wing truss. These horizontal trusses usually consist of the spars, two or more structural ribs, with diagonal members which may be wires, rods, or tubes. These diagonal tension members are known as drag wires, or drag struts. Each group of these elements—spars, compression ribs, and drag wires—forms a bay. Other ribs are included in them, the purpose of which is to preserve the fore-and-aft shape of the wing. These are therefore called former ribs. They also help to transmit the lift load from the fabric or skin to the spars.

In some wing designs, special compression struts take the place of compression ribs. All the ribs will then be former ribs. An exception to this lies in the use of false ribs in conjunction with the regular ribs. These false ribs are short ribs inserted between the former ribs to stiffen the loading edge of the wing. They run only from the loading edge back to the front spar or a little beyond it.

In the case of wood ribs, it is usual to make them in sections so that they can be attached to each side of the spars. When they are put in place they can then be tied together by means of a continuous flat strip of wood called a capstrip. Metal ribs, on the other hand, are generally built up as units, with clearance spaces for the spars to pass through. Nevertheless, they also have capstrips or wide metal flanges, to which the covering material, or skin, can be attached.

Metal ribs are built up in a variety of ways. Some of them are stamped out of sheet metal, with holes in the web for lightness, or struts formed in the stamping. Others are built up from metals of various sections, either welded or riveted together. The built-up ribs, both wood and metal, are assembled in jigs to assure uniformity.

In assembling the ribs on the spars they may be spaced anywhere from 4 to 20 inches apart, according to the type and purpose of the wing. Fast-flying aircraft, or others with heavy wing loading, require closely spaced ribs, or strongly built ribs with ample bearing surfaces.

To tie the ribs together at the nose of the wing (the leading edge), rounded strips of wood or metal are used. These form a smooth, rigid surface to support the skin at this important point. In the case of the trailing edge of the wing, a metal section is often used. This may be a V-shaped channel, or even tubing.

In practically all modern airplanes an essential part of the wing is the pair of lateral control surfaces called ailerons. The vertical and horizontal controls are mounted in the empennage where they have the advantage of great leverage on the wing in turning it about its vertical and transverse axes. The ailerons, which are mounted

in the wing, are given a maximum amount of leverage by being located as far as possible from the longitudinal axis of the airplane. As we mentioned earlier, they operate by lifting one wing, while pushing the other down.

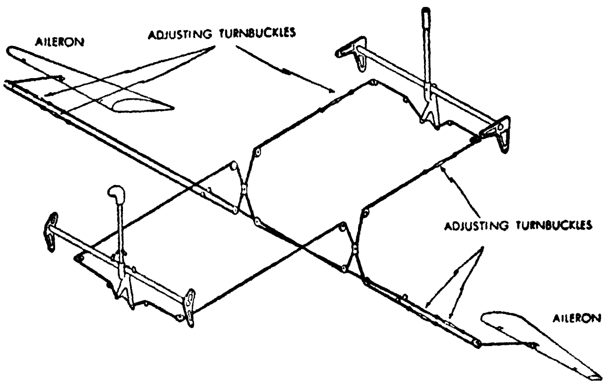


FIG. 42—Aileron control linkage for dual control

In all orthodox types of airplanes the ailerons are incorporated in the wing surface and form part of it when in the neutral position. They are operated by the sideways movement of the control stick, or wheel. Pushing the stick over to the right raises the right aileron and lowers the left one, so that the right wing goes down and the left wing goes up. On the surface, this may seem to be a perfectly simple operation which serves its purpose without any complications. Unfortunately, the two ailerons do not act in the same manner at the same time. The aileron that goes down increases the drag on that half of the wing more than the other one does on its half. This causes the plane to yaw (swing sideways), and this, in turn, makes the other wing swing forward, thus increasing its air speed. The greater speed tends to lift the lower wing and so bring the airplane back to a level position.

To overcome this difficulty, the Frise-type aileron was developed. In this aileron the leading edge of the raised aileron projects below the under surface of the wing. This increases the drag on that wing to partly counterbalance the increased drag on the other wing.

In place of the Frise aileron, and sometimes in conjunction with it, a differential aileron is occasionally used. This is simply an arrangement of the controls which makes the aileron swinging down move farther than the one going up.

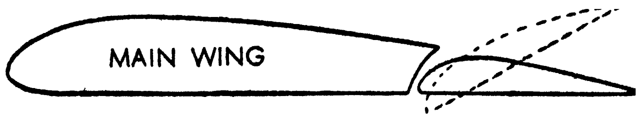


FIG. 43—Frise-type aileron

Ailerons are frequently fitted with small movable surfaces set into them in the same manner that the ailerons are set into the wing. The small surfaces are called tabs, and they can be adjusted so as to produce a continuous air pressure, either up or down, on each aileron. By this means, the airplane can be adjusted laterally for flying trim, but the adjustment usually has to be made while the plane is on the ground.

There are two important devices incorporated in many airplane wings to improve their performance under certain conditions. These devices are flaps and slots.

An airplane wing is designed to give a predetermined amount of lift at certain definite speeds and angles of attack, with a minimum of drag. Normally, at high speeds, not so much wing area is needed to give the required lift as at low speeds. Moreover, drag increases with the speed in proportion to the wing area. This means that while a small wing can be used for fast travel after take-off, it needs either more area or increased camber, or both, to provide the lift at low speeds for landing. Since the actual area of the wing itself cannot be changed in flight, some auxiliary device has to be used.

The commonest of these devices is the flap, which is applied to the trailing edge of the wing. Flaps increase the lift of the wing at low speeds, and, if sufficiently deflected, act as an air brake, thus permitting steeper glides and slower landings. Some types also are used to give extra lift during take-off. Several varieties of flaps are in general use, the commoner ones being the split flap, zap flap, and Fowler flap.

The simple flap is a section of the wing trailing edge, which can be turned down like an aileron—except that both flaps turn down at the same time. This type of flap cuts into the lifting surface of the wing and is therefore not so efficient as other types. Somewhat better is the split flap, which is a hinged section of the under surface of the wing. It is hinged along its forward edge and swings

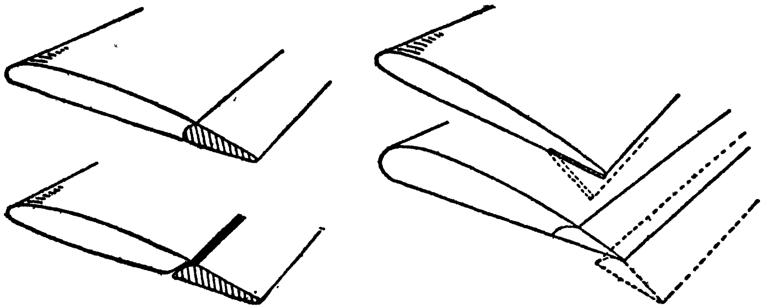


FIG. 44—Flaps: Upper left, plain; Lower left, slotted; Upper right, split; Lower right, Fowler

down, leaving a V-shaped gap between its upper surface and the wing.

The zap flap is an improvement on the split flap. The zap is similar to the split type, but has the additional feature of sliding backward as it opens. This keeps the rear edge of the flap in line with the trailing edge of the wing and increases its effectiveness. In the case of the Fowler flap, not only the wing camber, but the area of the wing is increased when the flap is opened. This flap is carried on slide supports extending rearward from the trailing edge of the wing. The flap, when not in use, is nested in the underside of the wing; in use it slides out bodily along the extended supports.

There are a number of other flaps developed for special purposes. One type is entirely separate airfoil spaced away from the under surface of the wing. This forms a very effective air brake, and yet may be used to increase lift under certain conditions of flight. More common than this are the diving flaps used on military airplanes. These may be of either the double or single types. The single flaps

may be of the split, zap, or, more rarely, the Fowler types. The double flap consists of a normal flap, opening downwards, and a duplicate

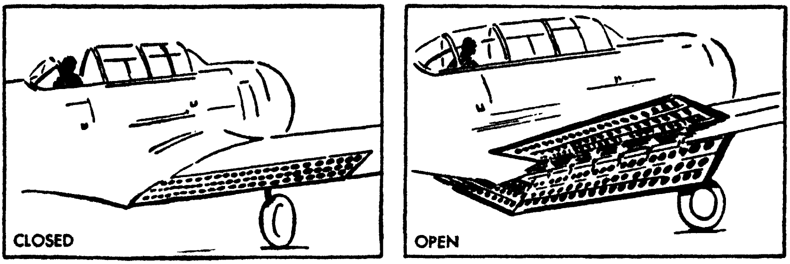


FIG. 45—Double diving flaps, perforated to reduce interference with tail surfaces

flap, hinged at the same point, opening upwards. For take-off and landing, the lower flap only can be used, but in order to limit diving speed, both upper and lower flaps are opened together, forming an air brake.

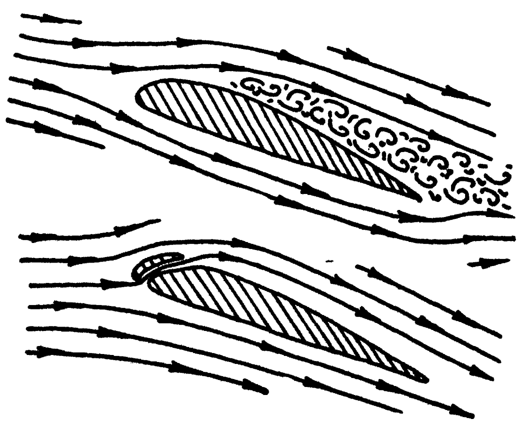


FIG. 46—Showing how a slot restores smooth airflow over a wing

In order that the open flaps will not interfere with the control of the plane by diverting the air stream away from the tail surfaces, the flaps are perforated with a large number of holes. These permit

sufficient air to pass through to maintain the flow over the control surfaces.

Another commonly used high-lift device is the wing slot. A slot is a long, narrow opening, parallel with the leading edge of the wing, connecting the upper and lower surfaces. At high angles of attack the slot permits air from the lower, high-pressure surface of the

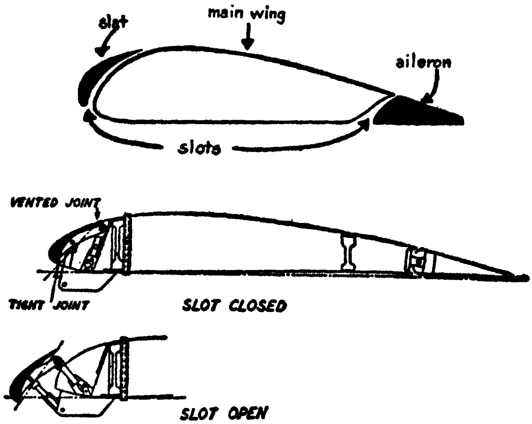


FIG. 47—Above: Two types of wing slots, one at the nose, the other between aileron and wing; Below: Slot control mechanism

wing to pass through to the upper, low-pressure surface. There it passes at high speed over the upper surface, stopping the air stream from breaking away from the wing surface, thereby causing burbling and loss of lift.

With such an arrangement, the burble point, and therefore the stalling angle, is delayed until the angle of attack is perhaps nearly double what it would be without the slot. The slot may be either fixed or variable, and the variable kind may be automatic in operation or controlled by the pilot. The arrangement of a typical controllable slot is shown in Fig. 47, Below. Here, the slot is formed by making the nose of the wing separate from the main portion. This leading edge portion, which extends across most of the wing, is attached to the front wing spar by means of sliding arms. These

arms move forward when the control mechanism is operated, separating the edge portion from the body of the wing.

Such slots, when automatically operated, depend on the distribution of air pressures to bring them into operation. At a low angle of attack, the leading edge is subject to pressures acting in a downward and rearward direction. As the angle of attack is increased, this load is reduced and the area of low pressure creeps toward the leading edge. When this reduced pressure reaches a certain value, the slot operating mechanism comes into operation.

The Empennage

The entire tail section of an airplane is called the empennage. It includes the stabilizers and the horizontal and vertical control surfaces—the rudder and elevators. The vertical stabilizer is called the fin, and the rudder is attached to it. The purpose of the fin is to provide resistance to any tendency of the airplane to swing sideways (yaw). It is a steadying influence in the horizontal plane which keeps the tail from wagging (oscillating). On single-engined planes the fin is set at a slight angle to the plane of symmetry, for the following reason.

The air stream from the propeller (the slipstream) does not flow in straight, horizontal lines over the wing and past the fuselage. It follows a helical (corkscrew) path, and therefore strikes the fin at an angle. The result is that the air pressure is greater on one side of the fin than on the other. Normally, this would tend to move the tail sideways. To counteract this tendency, the leading edge of the fin may be set at a slight angle to the longitudinal centerline of the airplane. As an alternative to the offsetting of the fin, a trim tab, similar to those mentioned in connection with ailerons, may be used.

The tab, you will recall, is a small, hinged surface inserted in the trailing edge of a larger control airfoil. The angle at which it projects into the air stream can be adjusted so that it applies a constant pressure on one side of the airfoil. This relieves the pilot of the necessity of holding over the control to correct some unbalanced

condition. In the case of the fin, the tab is set in the trailing edge of the rudder. In straight flight, of course, the rudder is in line with the fin and they act as a single airfoil; the tab really corrects the action of the fin.

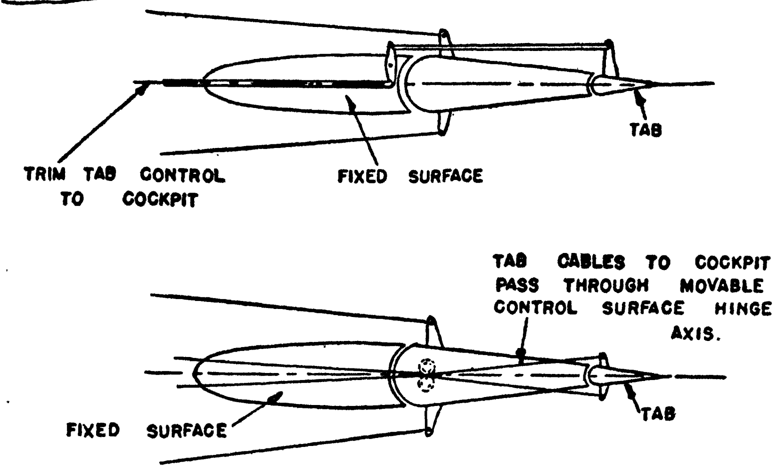


FIG. 48—Controllable trim tabs on rudder

The rudder is the movable vertical surface hinged to the fin. Its purpose is to turn the airplane on its vertical axis by swinging the empennage to one side or the other. This is accomplished by moving the rudder's trailing edge out into the air stream. This creates a difference of pressures on the two surfaces of the rudder, forcing it in the direction of the lower pressure. If the trailing edge of the rudder swings out to the left, the air pressures force the tail over to the right. This, in turn, swings the nose of the airplane to the left.

The movement of the rudder is controlled by pedals or a foot bar in the cockpit. Pushing the right-hand one swings the trailing edge of the rudder to the right and puts the plane in a right turn. The limit to which the rudder can be swung on either side of the fin is usually not more than 25 to 30 degrees.

As we mentioned in discussing the fin, a trim tab is sometimes incorporated in the rudder surface. This tab usually can be con-

trolled in flight. It can be used to counterbalance a load of any kind that would cause the plane to yaw. Without it, the pilot would be kept busy holding the rudder over slightly. With the tab, the air does the job for him.

Air pressures on a rudder at high speed are considerable, and turning the rudder in flight would require a certain amount of effort. To reduce the effort required, it is usual to counterbalance

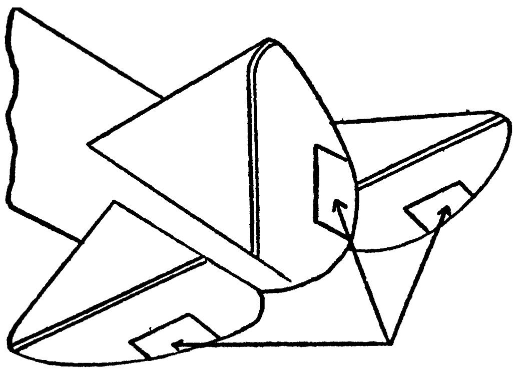


FIG. 49—Location of tabs on rudder and elevators

the rudder by extending a portion of its surface to the opposite side of the hinge. When the rudder is turned, this forward extension swings out on the other side of the fin. In that position the air stream strikes it, and the pressure so caused balances some of the pressure on the main surface of the rudder. This reduces the effort necessary to turn the rudder.

Because the vertical stabilizer is called the fin, the horizontal stabilizer can, without confusion, be called the stabilizer. When the fin and rudder are mounted centrally in the tail, the stabilizer is usually made in two sections extending horizontally outward from each side of the fuselage like a miniature wing. Attached to the rear edge of each half is a movable section mounted on a common axis. These two movable portions constitute the elevators (more properly called the elevator), and elevators and stabilizer are considered by engineers as one airfoil.

The fixed portion, or stabilizer, provides a constant resistance to any up-and-down movement of the tail, and so steadies the aircraft longitudinally. In other words, it checks a tendency to pitch. The stabilizer, in section, has a streamlined form, which, as a rule, terminates at the trailing edge of the elevator. The elevator, forming part of the streamlined airfoil, contributes to the stabilizing effect.

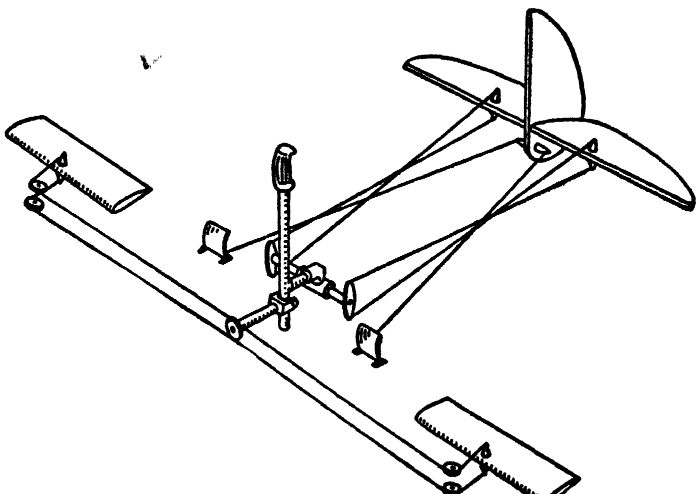


FIG. 50—Typical stick and pedal airplane controls

On some airplanes the leading edge of the stabilizer is adjustable vertically to a small degree. The air stream passing the wing is deflected downwards and so meets the stabilizer at an angle. Under certain conditions of loading, this might cause too much down pressure on the tail. Raising the leading edge of the stabilizer corrects this. Of course, not all single-engined airplanes have the stabilizer in line with the wing. Sometimes it is mounted high on the fin.

The elevators are controlled by the backward and forward movement of the control stick or wheel. Pulling the control back raises the elevators so that the nose of the airplane goes up. Pushing the

control forward dips the elevator and the plane goes into a glide or dive position. To reduce the effort required to operate the elevator, it is customary to arrange part of the surface ahead of the hinge line, as in the case of the rudder.

The elevators, too, may have control tabs which can be operated by the pilot during flight. In spite of the two elevator surfaces being on one shaft and rigidly aligned with one another, each is generally provided with a tab so as to equalize pressures on either side of the center. These tabs may be used to trim the plane for longitudinal balance due to loading or changes in speed of flight.

The Landing Gear

In order that an airplane may alight on, or take off from, the ground without damage to the main structure, a shock-absorbing undercarriage is needed. This structure is known as the landing gear and consists of pneumatic (air-filled) rubber-tired wheels, mounted on shock-absorbing struts. The standard, or conventional, arrangement is to have a main pair of landing wheels under the fuselage, ahead of the center of gravity, with a single small wheel at the tail.

With this arrangement, the struts to which the wheels are attached are made of a sufficient height for the propeller to clear the ground by at least 10 inches when the plane is in the horizontal take-off position. This has the further advantage of putting the airplane in a stalling position when making a three-point landing (touching the ground with all three landing wheels simultaneously).

On early types of airplanes the tail was equipped with a skid—a hardened steel shoe that dragged on the ground. This acted as a brake, and checked "ground looping" (a violent, uncontrollable turn on the ground). It did not help when the plane had to be moved, or in taking off. On most modern planes the tail skid is replaced by a small wheel, usually supported off-center so that it trails like a caster. On some of the larger planes this wheel is also steerable.

On some of the most recent types of airplanes a tricycle form of

landing gear is used. In the tricycle system, the two main landing wheels are located under the fuselage to the rear of the center of gravity. Instead of a tail wheel, the third wheel is mounted under the nose of the craft. This third wheel not only preserves the propeller clearance, but holds the plane in a normal take-off position.

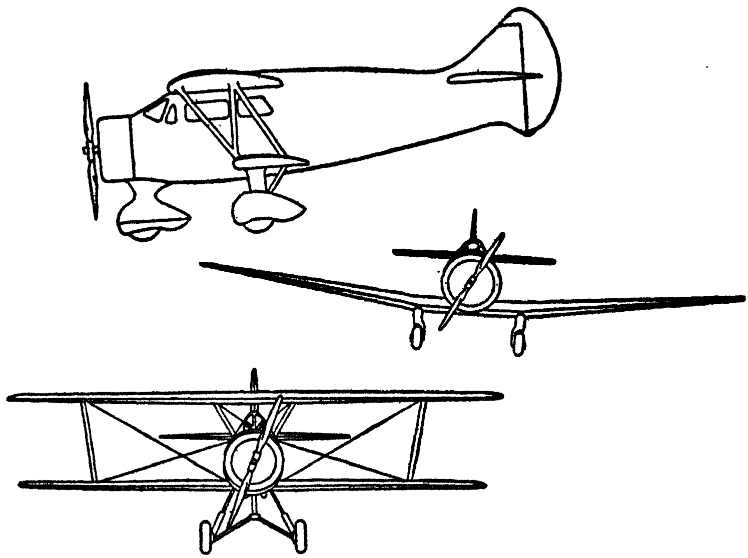


FIG. 51—Above: Tricycle landing gear; Center: Cantilever-type gear; Below: Split-axle type

In both types of landing gear the principal wheels are carried on shock-absorbing struts. In the tricycle gear the forward wheel is similarly mounted. On some airplanes the tail wheel, too, embodies a shock-absorbing device.

The simplest type of conventional landing gear is the cantilever strut. Various other combinations of levers and springs or flexible cords are used, but on the majority of planes special struts are used which will absorb shock without rebounding. These consist of telescopic struts, the action of which is checked by compressed air or springs, and the rebound retarded by oil which must pass through

small holes before the strut can extend itself again. These are known as oleo struts.

Most modern landing gears incorporate wheel brakes, sometimes even in the tail wheels. The main wheel brakes are operated independently of one another as an aid in maneuvering the plane on the ground. Operation is by toe pedals, usually pivoted above the rudder pedals, or by pressing down the heel on a hinged rudder pedal.

In order to cut down wind resistance in flight, landing gear units are often made retractable. That is, they can be withdrawn into the fuselage or wing. The non-retractable or fixed types are provided with streamlined coverings or fairings. Those which cover the wheels are, in the airman's language, "spats," and those covering the struts are "pants." All up-to-date landing wheels are fitted with low-pressure balloon tires.

CHAPTER VI

Flying Horsepower

IT TAKES power to pull an airplane through the skies, and that power must be available at the cost of little weight. This was the nightmare that haunted the early designers, who knew nothing better than bulky steam engines as a substitute for human muscle power. The age of flight began with the coming of the internal combustion engine, and that is what we are dependent upon today.

There are two kinds of internal combustion engines used on modern aircraft—the reciprocating engine and the turbine. The basic difference between them is the mechanical means by which they develop their power. Apart from this, both of them operate on the same principle—the direct conversion of heat energy into mechanical energy by the burning of a liquid fuel.

When gases are heated they expand. If they are heated in a confined space, they try to expand against resistance and so produce pressure. Under suitable conditions, that pressure can be made to do work. These facts form the basis on which airplane engines work. One way of applying heat to gases is to burn them. In airplane engines this is done by the ignition of a mixture of fuel vapor (gasoline, kerosene, or oil) and air. The burning mixture expands and so operates the engine.

The work that an engine will do is measured in terms of horsepower. One horsepower is defined as the amount of energy required to raise a weight of 33,000 pounds a distance of 1 foot in one minute —or 550 pounds 1 foot in one second, which is the same thing. While the usual definition specifies that the load is lifted, the same amount of power may be expended in other directions. For instance, a constant pull of 33,000 pounds may be exerted in a horizontal direction by a propeller. Over a period of one minute a total of one horsepower (written 1 h.p.) will have been expended.

The basic difference between the reciprocating engine and the

turbine is this: In the reciprocating engine separate charges of fuel are burned in cylinders in which pistons move up and down (reciprocate). In the turbine a constant flow of expanding gases revolves a turbine wheel.

Up to the present time, airplane engines have been almost exclusively of the reciprocating type, burning gasoline. Others, also of the reciprocating type, burn heavy oils and have a different means of igniting the fuel charge. These are called diesel engines, after their inventor, Dr. Rudolf Diesel. The turbines burn a lower grade of volatile fuel such as kerosene.

In all types of engines the fundamental operating requirements are the same, with the one exception that the turbine may be used either to turn a propeller, or to deliver a large volume of gases at high velocity to form a propelling jet. In all other instances, the engine is used to drive a propeller and must therefore deliver power in the form of rotary motion.

The Gasoline Engine

The requirements for a conventional type of airplane engine are: (a) some means of mixing the gasoline vapor with the proper amount of air to burn it entirely; (b) a container, in which the burning of the fuel can take place and the high pressure be developed; (c) an arrangement for introducing the mixture into that container, keeping it there as long as necessary, then releasing it; (d) a device for starting the combustion—i.e., igniting the mixture; (e) some means of converting the resulting gas pressure into mechanical motion, and (f) some way of emptying the container so that the operation can automatically be repeated so long as the fuel lasts.

All of these things are done by the engine, shown in diagram form in Fig. 52, page 90. This kind of engine is called an internal combustion engine because the fuel is actually burned inside it. A steam engine is an external combustion engine because the fuel is burned separately in a boiler.

In the diagram it will be seen that the requirements listed are all

met. The combustible mixture is provided by a separate instrument called a carburetor. The engine itself performs the rest of the functions except for the production of an electric spark to ignite the fuel. This electricity is provided by another instrument called a magneto.

The engine consists of the container, or cylinder, with a mixture inlet valve at one end. The ignition device is an electric spark

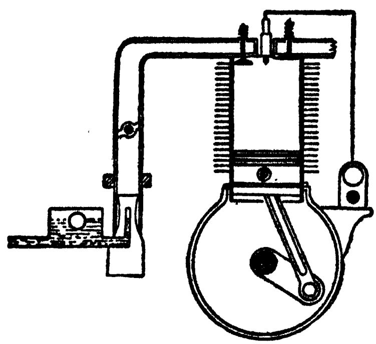


FIG. 52—Diagram of 4-stroke internal combustion engine

plug; the means of transmitting pressure is the sliding plug or piston which is free to move in and out along the cylinder bore, and a valve through which the burned gases can be expelled or exhausted. The piston can move only in a straight line, in and out of the cylinder. To secure the necessary rotary motion, the piston is connected by a hinged rod, called a connecting rod, to a crank supported in bearings.

When the piston moves outward from the cylinder it turns the crank in a half circle; when it moves back into the cylinder it pulls the crank through the second half of the circle, thus turning it one complete revolution. As the piston moves in and out, then (reciprocates), the crank and the crankshaft revolve, thus providing the rotary motion. Of course, if the crank is turned, the process will be reversed, and the crank will push the piston in and out of the cylinder.

All that is needed now is some means of synchronizing the various

operations, such as opening the proper valve and supplying the electric spark at the correct instant. Supposing, then, that these things are provided, and the engine is started by revolving the crankshaft. This sets in motion a sequence of operations that will continue as long as the fuel lasts. Starting with the piston as high in the cylinder as it will go, the first operation consists of opening the inlet valve which connects the cylinder to the fuel-air mixture supply (the carburetor).

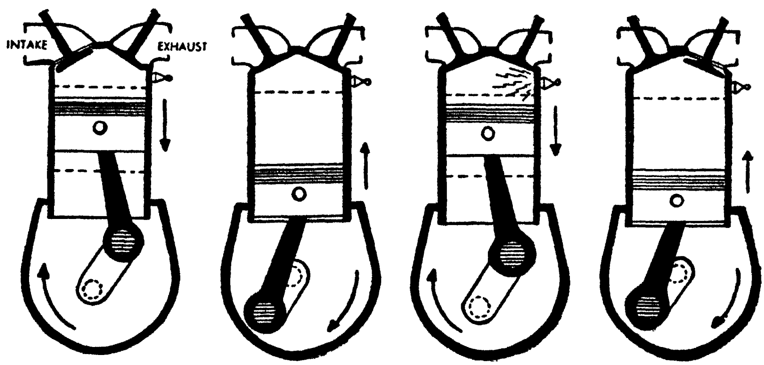


FIG. 53—The 4-stroke cycle engine principle

As the crankshaft is turned, the piston descends in the cylinder. Acting like a pump, it sucks in the combustible mixture. By the time it has reached the bottom of the cylinder the space above it is, theoretically, full of the gas. At that instant the inlet valve closes, leaving the mixture trapped in the cylinder. That is the end of the intake stroke.

With the crank still turning, the piston now rises in the cylinder, squeezing the gas mixture into a smaller and smaller space. This is called the compression stroke. When the piston has gone into the cylinder as far as it can (leaving only a small space above it for the compressed gas), and is ready to start moving out again, the spark occurs.

In a fraction of an instant the compressed mixture begins to burn. Great heat is generated and the pressure rises tremendously, push-

ing the piston down toward the open end of the cylinder. The engine has started! This is the first working stroke (the firing or power stroke). By the end of that stroke, most of the pressure is gone and the gases are of no further use. As the force of the firing stroke whirls the crankshaft so that the piston begins another upstroke, the exhaust valve opens.

The piston goes up once more, sweeping the used gases out of the cylinder through the exhaust valve port. By the time the piston reaches its uppermost limit of travel, the used gases are all gone, and the cylinder is ready for a new charge of the fuel-air mixture. Thus one complete cycle of operations has taken place in four strokes of the piston—intake, compression, firing, exhaust.

Engines which operate on this principle are called four-stroke-cycle engines, or simply four-stroke engines. Engines have been made which perform these operations in two strokes of the piston, but they are not used on American planes and only infrequently elsewhere.

In these two-stroke engines, the valves are replaced by openings (ports) in the cylinder walls, which the piston covers and uncovers as it travels up and down. The descending piston uncovers first the exhaust port, then the intake port. The fresh fuel and air mixture is supplied under slight pressure by a blower. As the intake port is uncovered, this compressed charge rushes into the cylinder from one side as the exhaust gases rush out at the other.

Diesel engines may operate on either the two-stroke or four-stroke-cycle principle. In the diesel, a charge of air is compressed very highly—500 pounds to the square inch, or more. This makes the air very hot. Into the hot air is injected a fine spray of fuel oil which immediately begins to burn. High thermal efficiency is secured through the high compression—that is, a great deal of the heat is actually turned into work—but the engine must be made heavy to withstand these operating pressures. Modified diesel engines, called semi-diesels, use lower pressures, and may have auxiliary electric ignition of the type used on gasoline engines.

Theory *vs.* Practice

The simple four-stroke engine described above has little in common with the present-day aircraft engine of that type. A great many considerations enter into the design and construction of such an engine that are not encountered in the theoretical engine. Some of these considerations are involved in the actual timing of the various processes during the four-stroke cycle.

Airplane engines run at fairly high speeds, the crankshaft revolving 2,000 times a minute or more, and the piston traveling at the rate of 2,000 feet or so every sixty seconds. Things must happen fast in an engine cylinder, and small variations in timing can make big differences in the output of power. Take valve operation, for instance.

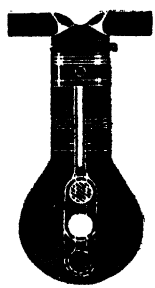


Fig. 54—Piston positions in 4-stroke engine—top dead center and bottom dead center (TDC and BDC)

Fig. 54 is a section diagram of a one-cylinder engine. The stroke of the piston is indicated. When the piston is as far down the cylinder as it will go, and the crank is in line with the connecting rod, the piston is said to be at bottom dead center (BDC). At the other end of the stroke it is at top dead center (TDC). If the engine is running at 1,000 r.p.m., it takes only half a thousandth of a minute for the piston to pass from BDC to TDC and vice versa. In that length of time an intake valve must open long enough to admit a full charge of mixture, and close before the piston reaches a point where it starts pushing the charge out again.

Because of the length of time that it takes to open a valve fully, the time it takes to speed up the flow of gas through the opening, and the gradual cutting off of the gas flow by the closing valve, exact timing of the whole operation is necessary. Furthermore, on the previous stroke (the exhaust), the exhaust valve is open to let the burned gases out. Theoretically, the valves should open and close exactly at the instant the piston reaches the end of its stroke. Actually, this is far from being the case.

In considering the relation of the piston movement to the valve opening, it must be remembered that the piston speed is not constant. At the end of each stroke the piston comes to a full stop before moving in the opposite direction. Moreover, because of the angle of the connecting rod just before and after BDC and TDC, the piston slows down during the last part of the stroke, and barely moves from a point at which the crank is at an angle of about 20 degrees before or after dead center.

The timing of the valves, therefore, is not merely a question of opening a valve at the beginning or end of a stroke. Actually, it is common practice to open the intake valve several degrees before TDC and to keep it open till 50 degrees or more after BDC. In the same way, the exhaust valve may open as much as 45 degrees before BDC and close at about 17 degrees after TDC. In such an instance, the exhaust valve would be open while the intake valve was open, during 25 degrees or more of crank movement. On the face of it, it would seem a mistake to have both valves open at the same time. Actually, the new gas rushing in may have a beneficial effect by helping to sweep out the exhaust gases.

In the same manner, the timing of the ignition spark is regulated. Ignition may take place up to 38 degrees before the piston is at TDC on the compression stroke. Usually the lead, as it is called, is 25 to 30 degrees before TDC. This gives the spark three to four thousandths of a second to do its work. The necessity for accurate spark timing is therefore obvious.

The Multicylinder Engine

One of the requirements of an airplane engine is a steady flow of power to keep the propeller turning. It must be obvious that an engine with only one cylinder cannot supply that kind of power because it provides only one power impulse for each four strokes

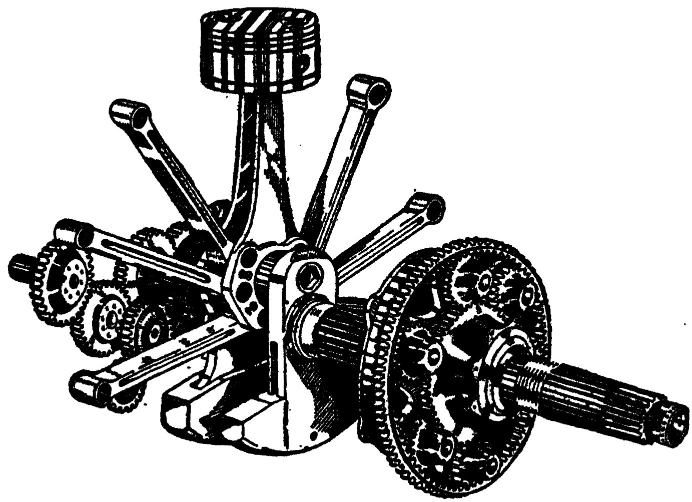


Fig. 55—Internal mechanism of 7-cylinder radial engine—cylinders and crankcase removed; also 6 of the pistons—with planetary gear which drives propeller shaft

of the piston—one for every alternate revolution of the crankshaft. A logical remedy for this is to use more cylinders.

With two cylinders there would be one power impulse every revolution. That would be a big improvement, but there would still be considerable fluctuation in the turning effort (torque) between firing strokes. The more cylinders used, then, the smoother will be the turning effort or torque. There is also another factor to be considered, and that is power output. With one cylinder, the amount of power that could be developed would be limited by the size of the cylinder. The power output and the evenness of torque

are therefore interconnected; the same solution works for both. That solution is more cylinders.

The addition of extra cylinders, however, is not altogether as simple as it sounds. The first problem to be solved is how to couple the cylinders so that they will work most effectively. Up to a certain point, the addition of extra cylinders improves the running quality of the engine. But we cannot go on adding cylinders indefinitely. The practical limit seems to be about twelve cylinders. Beyond that, if more power is to be had without increasing the cylinder size unduly, we have to build what is the equivalent of two (or more) engines working side by side.

Whether two or twelve cylinders are used, an important factor in their operation is the way the connecting rods are attached to the crankshaft. There may be a long crankshaft with a separate crank for every cylinder, or a shaft one half that length with two cylinders to each crank throw, and the cylinders at an angle to one another (or horizontally opposite), or the cylinders can be grouped radially, like the spokes of a wheel, around a central crankshaft with only one crank. There are several other possible arrangements, but these will suffice for illustration.

The arrangement and grouping of the cylinders is the basis of another system of classifying gasoline engines, as is the method of cooling. Engines in current use may be either air cooled or liquid cooled (not water cooled). Either of these groups may have any of the following cylinder arrangements: (a) all of the cylinders in one straight row, in line with the crankshaft (this is called the in-line type); (b) two lines or banks at an angle to one another, in line with a common crankshaft. This is the V-type; (c) two rows or banks lying horizontally, one row facing the other on opposite sides of the crankshaft. This is the horizontally-opposed type; (d) the cylinders radiating like wheel spokes around a single crankshaft. This is the radial engine. These basic arrangements may be added to or doubled to form H-, W-, or X-type engines or twin radials. The capital letters are used to indicate the cylinder arrangements when the engines are looked at from one end.

The in-line and V engines may be either upright (that is, with

the cylinders on top of the crankcase), or inverted, with the cylinder heads down. Not many upright in-line engines are now made. The inverted type works just as well and enables the propeller to be mounted well up from the ground without the engine covering (cowling) obstructing the pilot's view.

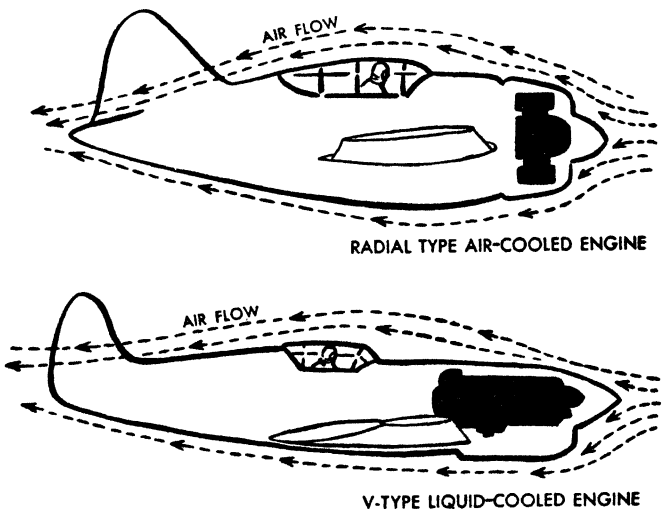


FIG. 56—Showing advantage of smaller frontal area of liquid-cooled engine compared with that of an air-cooled type

One factor influencing the design of airplane engines is air resistance. Theoretically, the smaller the area an engine presents to the air stream of an airplane in flight, the more efficient will the airplane be. The drag will be reduced and not so much horsepower will be required to overcome the engine's resistance to the air. This is one important argument in favor of the liquid-cooled engine.

The liquid-cooled engine can be totally enclosed in a streamlined covering or in a wing, and the fuselage, or nacelle, which houses it can be properly streamlined. On the other hand, such an engine requires a radiator and an oil cooler, both of which offer resistance to the air. Therefore, while these liquid-cooled engines can be placed anywhere in the fuselage—as in the case of a noted warplane,

in which it is located behind the cockpit—any measure of air resistance must include that due to radiators. In addition, the liquid-cooled engines are handicapped by the weight of the liquid, the radiator, and the connecting piping, which is commonly referred to as the plumbing.

Since both the inverted in-line and the inverted V-type engines are made in air-cooled models, the problem of efficient cooling by that medium has received considerable attention. In both these types the engine is installed head-on to the air stream. This means that, normally, the front cylinders would receive most of the cooling blast. Furthermore, the leading cylinders would be cooled more at their front sides than at the rear. This might well lead to unequal expansion and distortion.

One of the most important features of these engines, therefore, is the arrangement of the cooling air deflectors. Through extensive experiments, engine cowlings and air deflectors have been developed which utilize air speeds and pressures to give equalized cooling under the severest operating conditions, without unduly increasing drag due to air resistance.

In the case of radial engines the problem is much simpler, since a larger head-on cooling area is available. Even here, however, the twin radials in which one row of cylinders is partially obscured by that in front of it, careful design of air deflectors is essential. In addition, it is common practice to allow for differences of heating between front and rear cylinders in the timing of the spark. In the hotter rear cylinders the spark is retarded slightly because those cylinders normally would fire ahead of the cooler front cylinders.

LUBRICATION

Effective lubrication is essential in all heavy-duty machines. In aircraft engines it is vital, not only as a means of reducing friction, but as an aid in cooling the interior parts. Aircraft engines work at high pressures and temperatures, and they are called upon to develop something approaching their maximum power continuously for long periods of time. Obviously, therefore, no hit-and-miss

system of lubrication will do. It must be positive and continuous. The only way to insure this is to feed oil to the main rotating surfaces under pressure. This is the general practice on all current airplane engines, but the method by which it is done varies. There are two main forms of lubrication, the wet-sump system and the dry-sump system.

On early types of gasoline engines it was the practice to lubricate the moving parts by allowing the cranks to dip into trays of oil and splash the lubricant all over them. This was called the splash system, and it served moderately well on light-duty engines. When force-feed systems of lubrication were developed, the splash system was retained as a means of getting oil on cylinder walls and other places where it was impracticable or too costly to apply positive lubrication.

An adaptation of this system is used on modern engines to lubricate the cylinder walls and piston bearings. But instead of oil trays, the oil is fed through holes in the crankshaft to the main and crank bearings, under pressure. Oil escaping from the crank bearings is thrown into the cylinder barrels by the whirling cranks. In addition, the revolving parts break up some of the loose oil into an oil fog which covers every part in the crankcase with a film of oil.

Both the wet-sump system and the dry-sump system employ pressure feed to the principal rotating parts, and sometimes to the valve mechanisms on the cylinder heads. In the wet-sump system the oil supply is kept in the crankcase sump (a well or reservoir in the crankcase base). This system obviously cannot be used on radial engines, nor on planes used for much acrobatic flying. In practice, it is restricted to the smaller engines.

Since the oil serves an important purpose in helping cool the engine, some provision must be made for cooling the lubricant itself. In the wet-sump type, the crankcase sump is often ribbed on the outside so that the air stream can effectively cool it. Circulation under pressure is effected by a gear-type pump in the sump, with which is incorporated an easily accessible strainer.

In the dry-sump system, the pressure feed is practically the same

as with the wet sump, but it may be located externally. In addition, there may be a scavenger pump to draw off the circulated oil and pass it on to an external oil tank. Since there is no loose oil in the engine, there is no fear of the lubricant collecting in the upside-down cylinders, or in an inverted or radial engine. Instead of one capacious sump, engines employing the dry-sump system of lubrication have one or more points to which excess oil can drain. The oil is drawn off from these points by the scavenger pump. It is then circulated through a cooling radiator and back to the external oil tank. Thus there is no oil in the engine except that in actual circulation.

Cooling

Inside an airplane engine cylinder, the temperatures generated vary from several hundred to several thousand degrees. The engine therefore becomes hot. Some of the heat escapes in the released exhaust gases; a great deal of it leaks through the cylinder walls and head, and some through the piston. Everything in contact with the burning gases conducts away some of the heat. If there were no way by which the heat could escape from the cylinders, the parts would quickly become so hot that the engine could not work. The valves would warp, or even melt; lubrication would be destroyed and friction would increase tremendously so that the piston would become immovable in the cylinder. It is therefore necessary to maintain the engine at a reasonable working temperature without reducing its efficiency by over-cooling.

Cooling of the air is effected by the circulation of air, or of some liquid having a high boiling point, over the hottest parts. Cooling by air is effected by exposing the cylinders to an air stream created by the engine propeller or by the motion of the plane in flight. To secure the best possible cooling effect, the cylinders and heads are formed with fins or thin ribs extending from their surfaces and parallel with the flow of air. This presents a maximum of cylinder area to the cooling air. Cowls or deflectors are used to direct the air where it is most needed.

On liquid-cooled engines, the cylinders and heads are fitted with coverings or jackets so that a stream of liquid (ethylene glycol) can be made to flow over the heated parts. The liquid is kept in constant circulation by a pump, and it, in turn, is cooled by passing

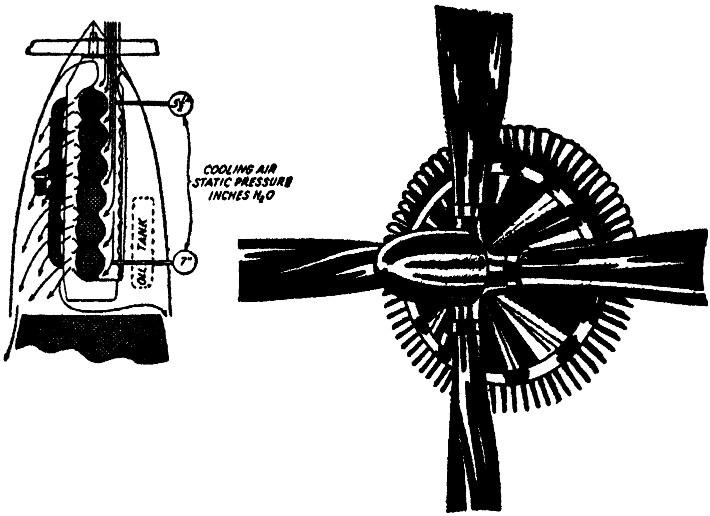


Fig. 57—Left: Baffle system of air-cooled in-line engine; Right: A special fan for cooling radial engines at low air speeds, shown attached to the propeller

it through a radiator exposed to the air stream. The piston and other internal parts of the engine are cooled by the circulating oil which comes in contact with them. This, too, is cooled by radiation, as we mentioned before.

Mixing and Firing the Fuel

The fuel of a reciprocating engine consists of a mixture of gasoline vapor and air in certain definite proportions (thirteen to eighteen parts of air to one of gasoline, by weight). The job of the carburetor is to convert the liquid gasoline into vapor and mix it with the right amount of air. And it must keep on doing that when the engine is running slow or fast, at sea level or high in the air.

The simplest carburetor consists of a valve which regulates the flow of gasoline into the carburetor, a venturi passage through which air is drawn by the suction of the engine, and a fine tubular orifice or jet through which the gasoline passes to mix with the

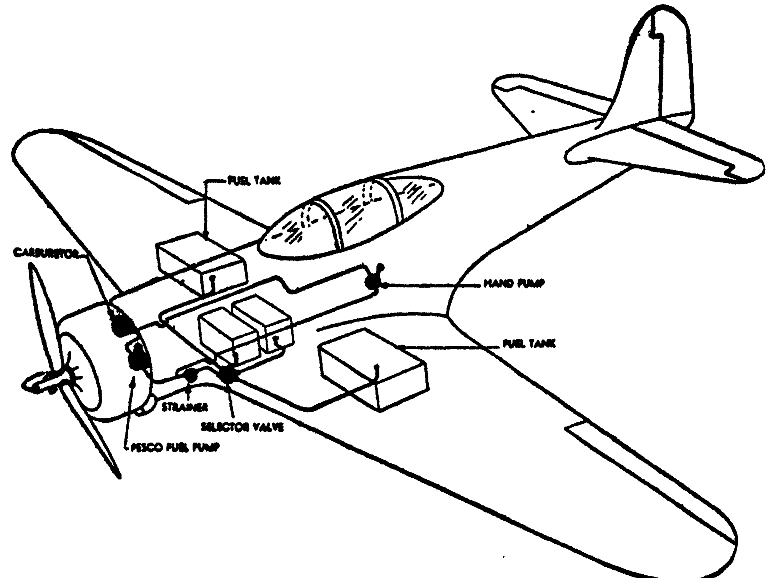


Fig. 58—Typical fuel system

air rushing past it. The gasoline is supplied by gravity from a tank at a higher level than the carburetor, or from a lower tank (often in the wing) from which it is pumped.

The gasoline enters the carburetor, through a valve, into a float chamber. This is a small metal box enclosing a light hollow metal float. When gasoline enters the chamber, the float rises and gradually closes the needle-type valve which shuts off the gasoline. The valve is set so that the float chamber is always filled with gasoline to a predetermined height.

From the float chamber the gasoline passes to the jet in the venturi throat. When the engine is not running, the gasoline level is kept just below the top of the jet. When the engine is started, the

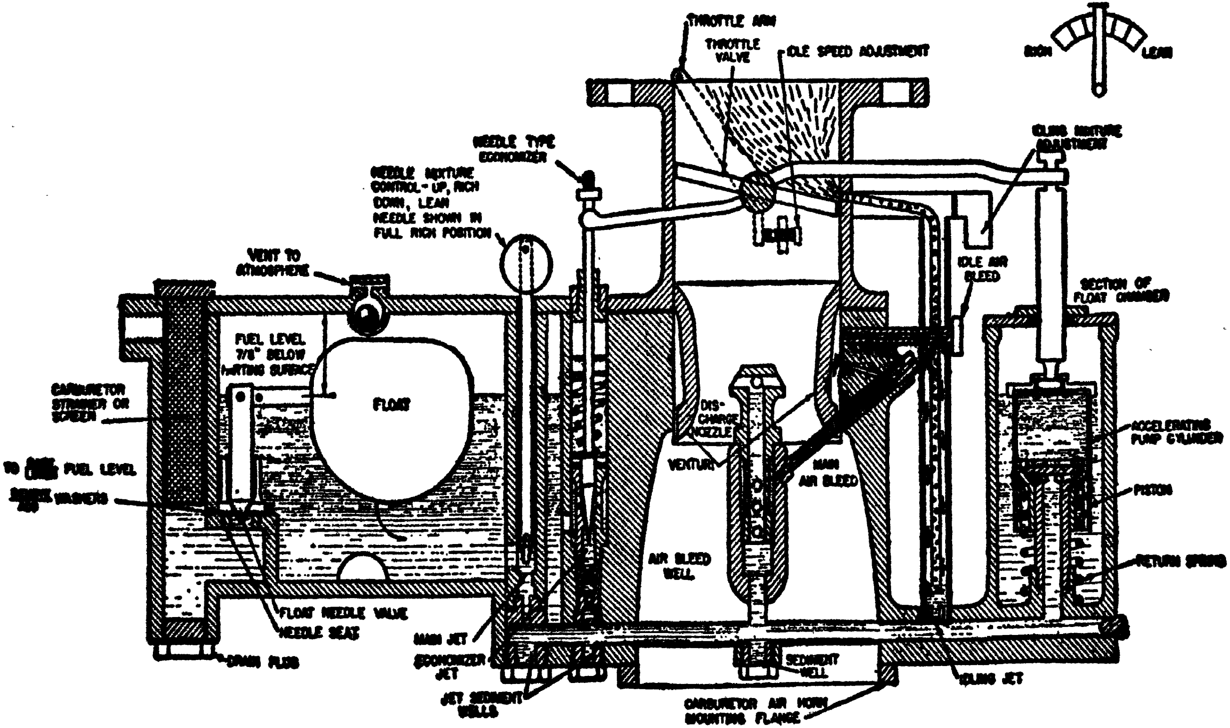


FIG. 59—Schematic view of a single-barrel carburetor

air rushing through the venturi becomes lower in pressure than the air in the float chamber. Consequently, the gasoline spurts out of the jet in the form of a fine spray. Mixed with the fast-moving, whirling air, the spray quickly turns to vapor, and passes through an intake pipe or manifold to the engine cylinders.

Just above the jet is a throttle valve, by means of which the flow of mixture to the engine is regulated and the engine speed controlled. This valve is simply a flat metal disk inside the round pipe. When the disk is in line with the sides of the pipe, it offers practically no obstruction to the flow of the mixture. The more it is turned across the bore of the pipe, the less mixture can get past it.

Modern carburetors, naturally, are far more complex than this. For one thing, the flow of gasoline from the jet is not proportionate to the volume of air rushing past it at all throttle openings or settings. Nor will the flow of gasoline keep pace with the airflow if the throttle is suddenly opened. These things have to be compensated for by special idling jets (idling means running slowly under no load), and accelerating wells or pumps.

Provision also has to be made for regulating the strength of the fuel mixture according to the requirements of the moment. An engine accelerating or climbing needs a richer mixture (one with more gasoline in it) than it does when it is cruising, and so on. The flow of fuel also must be regulated in accordance with the air pressure changes, due to variations in altitudes at which the plane is flying. Some of the compensating devices are automatic and some have to be manually operated by the pilot.

One of the most important factors affecting carburetor operation is the pressure of the external atmospheric air. At sea level, the air pressure is around 14.7 pounds to the square inch. At an altitude of 20,000 feet it is only about half that much. Therefore, as an airplane ascends, the engine draws in less and less air, and its power falls off accordingly. The only satisfactory way of counteracting this loss of power is to pump more and more gasoline mixture into the cylinders. The apparatus used for this purpose is the supercharger.

The supercharger is a pump of a special kind. Most of those in

current use are of the centrifugal type. They consist of a circular disk having radial vanes on its face, which revolves at high speed inside a casing. This disk is called an impeller, and the mixture enters at the center around the drive shaft and is thrown outward, toward the circumference, by the vanes. Around the impeller is a ring of stationary vanes forming curved and tapered channels.

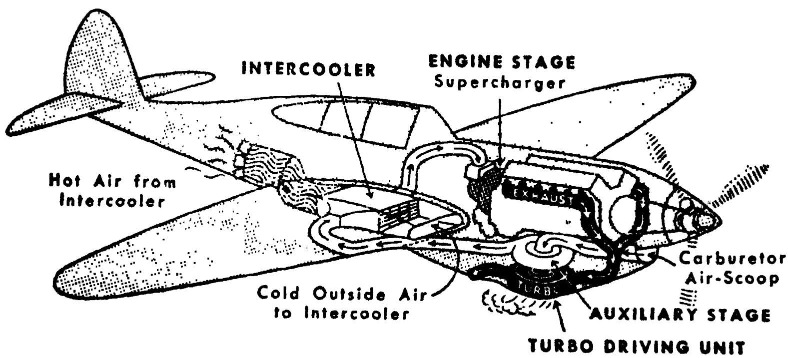


FIG. 60—Aircraft supercharger system

This is called a diffuser. The mixture, leaving the impeller at high speed, is slowed down by the diffuser so that its pressure rises. The compressed mixture then flows to the cylinders. In this way more mixture is forced into each cylinder than would normally be drawn in. The engine therefore produces more power.

This excess of power can be used at sea level when it is needed during take-offs. It can also be used to compensate for loss of air pressure up to moderate altitudes—say 15-20,000 feet. But at those altitudes this supercharger would not be able to maintain the full power output of the engine, and for proper operation something more is needed. This supercharger is located between the carburetor and the engine, and it compresses the air-fuel mixture. It is therefore called an internal, or engine, supercharger. Since its efficiency falls off with increasing altitude, because of the decreased density of the air, it is necessary to increase the pressure of the air supply also. This is taken care of by another supercharger lo-

cated between the air intake and the carburetor, and is therefore called the external or auxiliary supercharger.

If, as is commonly done, the external unit is driven by a turbine wheel operated by the exhaust gases of the engine, it is called a turbo-supercharger. When both superchargers are used together it is necessary to cool the compressed air which becomes very hot when it is squeezed into a smaller space. It is therefore passed through a radiator called an intercooler. If such a radiator is used between the second (engine) supercharger and the engine, to cool the mixture, it is called an aftercooler.

With both superchargers in use, airplane engines can be made to operate at 50,000 feet or more without a serious loss of power. Either manual or automatic (electronic) controls can be used with the superchargers to regulate the amount of boost they give to the air and mixture in accordance with the altitude. Overboosting places a great strain on the engine by making it deliver more power than it was designed to develop, and, in a short time, would do irreparable damage. The pilot can always tell whether or not the engine is getting the required amount of fuel mixture by means of a meter which registers the pressure in the engine intake manifold.

Creating the Spark

On almost all airplanes the source of high-voltage electricity for the ignition is a magneto. This is an electrical generator of a special type. Like all generators, it consists of coils or windings revolving in a magnetic field, or a moving magnetic field fluctuating over stationary coils. The latest types of magnetos utilize the latter principle. Such a magneto consists of copper wire wound on an iron frame which forms its core. An extension of the core forms pole pieces between which a magnet revolves. The movement of the magnet creates a fluctuating magnetic field in the core, and this in turn induces an electric voltage in the first, or primary, winding of the coil.

The fluctuating (alternating) voltage in the primary induces a current of higher voltage in the secondary winding wrapped around

the primary. By means of a small cam on the magneto shaft, the voltage in the primary is broken or interrupted at regular intervals. This sudden stoppage of the current produces a violent surge of current in the secondary winding, of a tremendously higher voltage —generally around 24,000 volts.

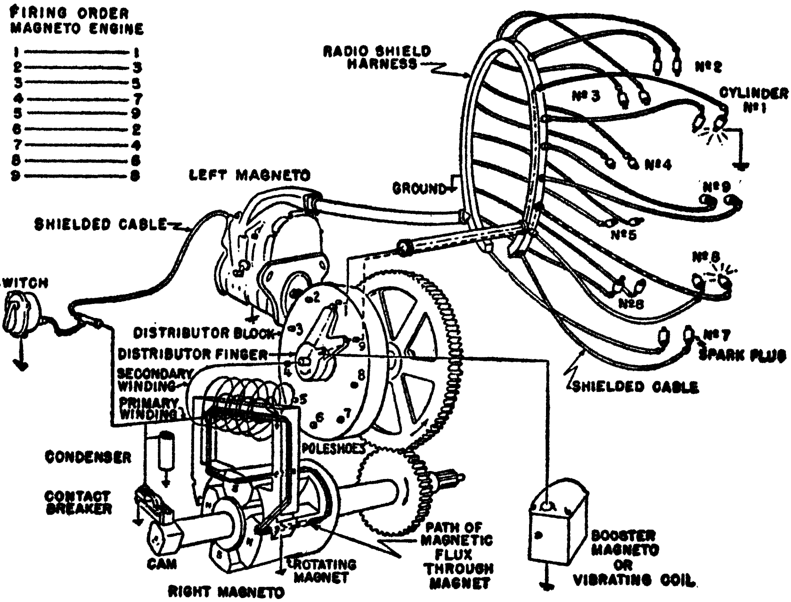


FIG. 61—Diagram of dual magneto ignition system

At that instant, the secondary winding is connected to the spark plug, and the high voltage creates a hot spark which leaps the gap between the plug points. By means of rotating contacts, called a distributor, the voltage is fed to the plugs in proper sequence so that each cylinder fires at the correct instant. The spark plug is merely an artificial gap in the circuit. It consists of a metal body which screws into the cylinder, an insulating core of mica or some ceramic inside, which is the electrode (electrical terminal) connected to the magneto.

This central electrode forms one side of the gap, the other elec-

trode being attached to the plug body. The electricity therefore travels through the circuit formed by the magneto secondary winding, the distributor, the plug cable, the plug gap, the plug shell, the metal of the engine and the magneto base attached to it.

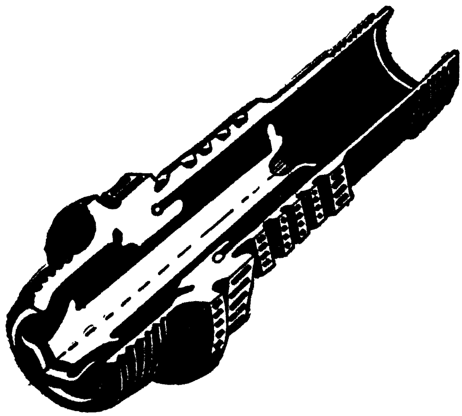


FIG. 62—Section through a typical aircraft spark plug

In most of the smaller airplanes, and in all having engines of over 200 h.p., two plugs are used in each cylinder, fed by two magnetos or one dual magneto, both to give greater efficiency and as a safety precaution.

THE TURBINE ENGINE

Unlike the reciprocating engine, the turbine develops its power solely through rotary motion. It has no valves, cranks, or pistons. The main element of the turbine is a wheel or drum, with a large number of thin metal blades or vanes attached to its circumference. These blades are of airfoil section, and are set at a small angle to the wheel axis. They form tapering channels through which the expanding gases of the burning fuel can pass.

The turbine wheel is entirely enclosed except for the two annular (ring-shaped) openings on opposite sides of the vanes. One of these openings leads from the combustion chamber, and the other

leads to the exhaust duct. Coupled to the turbine shaft is a rotary-type (centrifugal) compressor. Revolving at high speed (around 30,000 r.p.m.), the compressor packs air at high pressure in a ring-shaped combustion chamber. The fuel is injected into this chamber, and the resulting combustion takes place as the burning mixture passes through the turbine vanes.

The gases expanding through the vane passages revolve the wheel, at high speed, through the reaction of the jets and the blade pressures created as the high velocity gases sweep over the airfoil-section vanes. In some designs of turbine the combustion uses only about 20 per cent of the air supplied by the compressor. The rest of the air is used to reduce the temperature of the gases and cool the engine.

The power delivered by the turbine is available to drive a propeller, or the exhaust gases can be adapted to jet propulsion. This is discussed in detail under "Propulsion Systems." At the present stage of development, gas turbines consume but little more fuel than the reciprocating type of engine and they can be made to deliver twice the horsepower for about half the weight. Units of very high power are therefore comparatively simple to produce, and they are equally simple to operate and to service.

CHAPTER VII

Props, Rotors, Rockets, and Jets

THE great majority of all airplanes at the present time are pulled through the air by a device known as a propeller. The only serious competitor that the propeller has, as yet, is the jet, though that

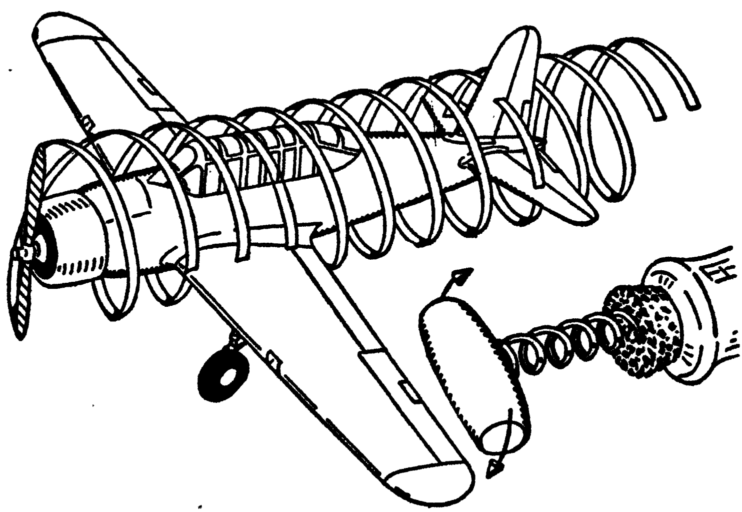


FIG. 63—Analogy between action of propeller and corkscrew

competition is likely to grow stiffer as time goes on. Jet propulsion, it must be admitted, has exciting possibilities. On the other hand, it has severe limitations and it cannot be applied to all aircraft indiscriminately. The propeller, therefore, is likely to be with us for some considerable time to come.

Like the airplane itself, the propeller has undergone considerable change since the early days of flying. Originally, the propeller was something like a fan, with very wide, tapering blades made of flat wood twisted to give them pitch. It worked like a screw, pulling

itself through the air when it was rotated by an engine. When airfoil shapes came to be investigated, it was found that the propeller could be made a great deal more effective by using blades of true airfoil section.

Today, the blade of any propeller, whether of wood or metal, is very much like an airplane wing in section, and it works in much the same manner. Cutting through the air, the blade pushes air back with its flat face, and at the same time reduces the air pressure over its cambered back. What it is actually doing is creating "lift" in a more or less horizontal direction. That lift is pull, or thrust.

Propellers consist of two to five blades attached to a central hub. The number of blades used depends upon the amount of power to be absorbed by the propeller, and is governed by the permissible diameter. For example, if a three-bladed propeller needs to be made larger to handle more power, it can be increased in diameter. But if, for structural or other reasons, the airplane cannot use a propeller of greater diameter, more blades must be added.

Light planes usually have a two-bladed propeller, the three- and four-bladed units being used with engines of high horsepower on transports and fighter planes. Five-bladed propellers are uncommon, but they are used on some of the world's best-known military planes—the British Spitfires. A single-bladed propeller has been developed, with the one blade balanced by a counterweight, but it is not used at the present time.

Because five blades are about the practical limit for any single propeller, extra blades can only be added by using two propellers in tandem. With one propeller behind the other on the same shaft, they are rotated in opposite directions. Such coaxial, contra-rotating propellers have the advantage of eliminating the torque reaction produced by single propellers.

Any modern propeller, therefore, is a rotary airfoil or group of airfoils. And, like other airfoils such as a wing, they are limited as to the speed with which they can cut through the air. Improvements are being made in propeller design from time to time, but at present there seems to be a limit of 18 feet or so in diameter. This

is due to the fact that the drag on the blades increases enormously as their tip speed approaches 1,100 feet per second—the velocity of sound. A very large propeller, therefore, would have to revolve so slowly that its efficiency would be seriously reduced. On the other hand, since we now have wings that will permit the planes to fly

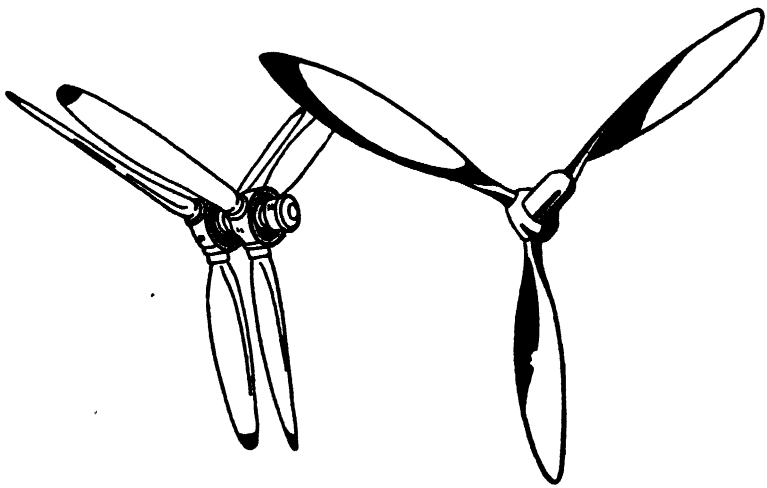


FIG. 64—Left: Contra-rotating coaxial propellers; Right: A 3-bladed propeller

at ultra-high speeds (sonic speed—the speed of sound), it is logical that a propeller also may be developed which will work at the same speeds. As it is, propellers are used even now to drive airplanes at speeds up to 500 m.p.h.!

One important difference between a wing and a propeller blade is this: The whole leading edge of the wing travels through the air at the same speed (in straight flight), but the entire leading edge of the blade does not. The tip of the blade may actually move six or seven times as fast as the blade root. Since the work done by the blade depends upon its speed, as well as the angle of attack, if the speed varies so should the angle. The faster the blade part moves, the smaller the angle it needs to present to the air. That is why

a propeller blade varies both in shape and pitch angle throughout its length.

The actual angle at which the blade is set in its hub depends upon the speed at which it is designed to operate most efficiently. That speed, in turn, is governed by the amount of power the propeller is intended to absorb. In other words, the simple, fixed-pitch propeller is made to work with an engine of a certain horsepower and at some average rate of revolution, and its size and blade angle are fixed accordingly.

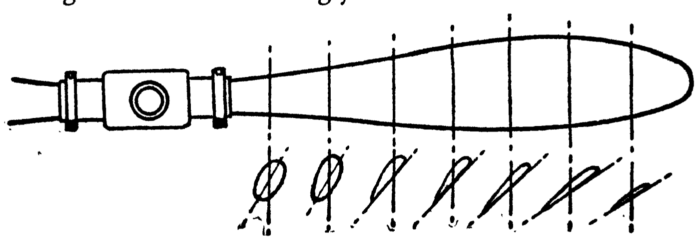


FIG. 65—How propeller blade sections change along their length

Like a wing, a propeller blade produces "lift," which is called thrust, and it is subject to the same kinds of drag. Both thrust and drag are changed as the blade speed is changed, and they also change with any change of blade angle. When a propeller is operating at its point of best efficiency, the thrust is greatest in proportion to the drag. This happens when the blade angle is slightly greater than the angle of relative wind. The relative wind is the angle at which the leading edge meets the air, and when the airplane is in flight, that angle depends upon the forward speed as well as the blade pitch.

While a plane is standing still on the ground with the propeller turning, the relative wind will be at right angles to the propeller shaft. Therefore, the drag will be least when the blade is set at only a very slight angle. As soon as the plane begins to move forward, the angle of relative wind increases. But at a low air speed, the wind angle will still be small, and the pitch of the propeller can be kept very low.

When the plane is in the air, and moving along at cruising speed,

the increased air speed has increased the wind angle. Therefore, the pitch of the propeller (the angle of the blades) must be increased in proportion. This means that the propeller will take bigger bites out of the air during each revolution, but it will be revolving at a slower rate. In other words, the faster the plane moves through the air, the greater should be the blade angle of attack. With a fixed type of propeller this is obviously impossible.

On light planes solid propellers of wood or metal are often used, and since there is no wide range of flying speeds, their average efficiency is not too low. But for larger and faster planes, the fixed propeller is seriously inefficient. A plane equipped with such a propeller is like an automobile with a single gear. This fact has been recognized for a long time and propellers have been, and still are, made with blades that are adjustable when the plane is standing still on the ground. Such propellers can only be adjusted for some special set of conditions and they will not be efficient under any others. The ideal solution is to have a propeller, the blade angle of which can be adjusted while the plane is flying. Several types of propellers are available which permit this to be done.

The simplest kind, probably, is the controllable pitch propeller, with which the pilot can set the blades at a low angle for take-offs and at a high angle for cruising. These positions are fixed by the limits to which the blades can be turned. Several methods are available for changing the pitch—mechanical, electrical, or hydraulic.

On one well-known type of controllable pitch propeller, the centrifugal force of weights mounted on the hub is used to turn the blades to high pitch. Oil pressure is employed to return them to low pitch. The weights are coupled to the blades by gears. When the propeller is revolving, the weights pull outward so that they tend to increase the blade pitch. The faster the propeller revolves, the greater the force with which the weight pulls. Therefore, as soon as the propeller speed reaches a certain number of r.p.m., the pitch of the blades is increased. This causes the air load on the blade to become greater, and this drag slows the propeller down.

The other part of the mechanism consists of an arrangement for

feeding oil from the engine oil supply under pressure to a cylinder in the propeller hub. This oil pressure is made to counteract the pull of the flyweights. The oil pressure is controlled by a valve which the pilot can operate. If he turns it to low pitch, the propeller

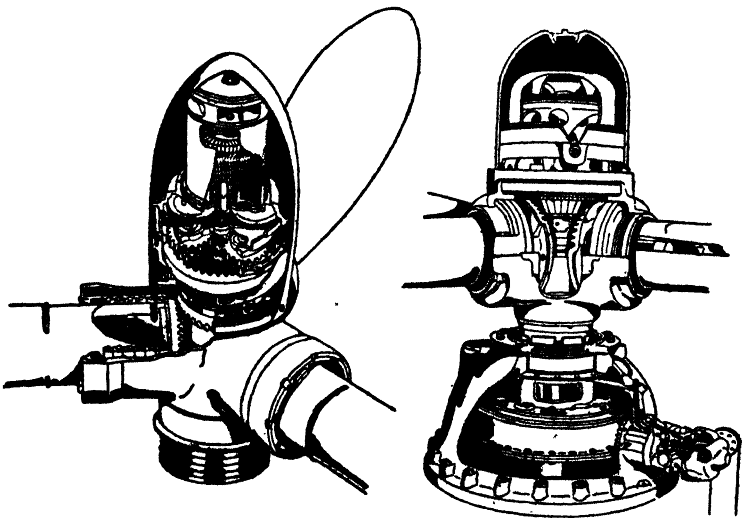


FIG. 66—Left: Interior view of Curtiss Electric constant-speed propeller; Right: Hamilton Standard constant-speed propeller, hydraulically operated

cylinder is pushed forward by oil pressure. The cylinder is linked to the counterweights and pulls them toward the center, thus turning the blades into low-pitch position. If the pilot turns the valve to the high-pitch position, the oil drains from the cylinder back to the engine circulation system. There is then no pressure on the cylinder to counteract the pull of the flyweights. The weights then pull outward, turning the blades into high-pitch position.

This type of propeller is fairly simple in construction, but, naturally, it is a great deal heavier than the fixed-type propeller. In many instances, the extra weight is more than offset by the saving in fuel and increase in over-all efficiency of the engine-pro-

peller unit which forms the power plant. This is, however, a compromise at best. To secure the greatest possible efficiency, it is necessary to have a propeller which permits of the blade angle being adjusted throughout the complete range from low to high.

With such a propeller, the ideal condition can be achieved by having the engine revolve constantly at its most efficient speed, changing only the propeller pitch according to the work it has to do at the moment. Such propellers are called the constant-speed type, and the pitch of the blades is changed automatically in flight. The pilot ordinarily does not need to touch the pitch control mechanism, but he can, if he wishes, reset the limits to which the blades can be turned. On one propeller of this type, the pitch is set by a separate unit, called the constant-speed control. The operating mechanism, as far as the hub is concerned, is the same as that of the controllable pitch type just described. The principal difference is that the oil supply is automatically regulated by the constant-speed control.

This control mechanism consists of a sliding valve operated by the movement of a pair of flyweights, revolved either by the airplane engine or by a special motor synchronized with it. The faster the engine goes, the wider swing the weights, lifting the valve which controls the flow of oil to the pitch operating mechanism in the propeller hub. The movement of the flyweights is regulated by the pressure of a spring, and the pressure of that spring is controlled by the pilot from the cockpit or cabin.

As the constant-speed control regulates the speed of the propeller, it also controls the speed of the engine. The engine speed, therefore, is actually regulated independently of the throttle. These particular constant-speed propellers are made so that the pitch of the blades can be changed 10 degrees on one model and 20 degrees on another. For planes on which high supercharging is not used, the 10-degree type is quite sufficient. The 20-degree type is intended for high-performance aircraft operating at high altitudes.

A great many airplanes are being built which not only travel at very high speeds, but climb to enormous heights and are called upon to dive under power. Such airplanes, naturally, need propellers with unusually large ranges of pitch adjustment.

On other kinds of airplanes which have more than one engine, there is sometimes a need for stopping the propeller entirely. This

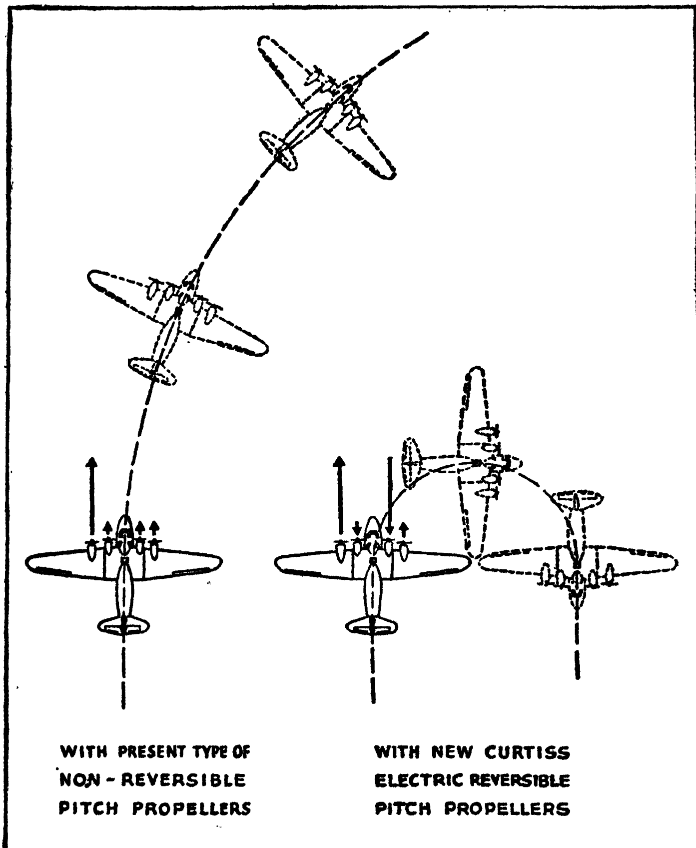


FIG. 67—One advantage of reversible propellers; another is to check speed on the ground in landing

has been done, in the early days, by putting brakes on the propeller shafts. Stopping a propeller in that way, however, is a slow business when every second counts. With an engine damaged, a propeller that is being turned by the wind (windmilling) can do a lot of

harm in a short time. Not only that, but an idle propeller offers a great deal of resistance to the forward motion of the airplane. The cure for this is to turn the blades edge-on to the wind. This is called feathering, and propellers are now made which will do this.

On these propellers, which are called the full-feathering type, the blades are turned instantly to an angle of about 87 degrees. Since the blade is not a flat piece of metal, but is twisted instead, this is the best average position at which the wind resistance is practically nil. This feathering is, of course, intended only for emergencies. If the blades got into that position accidentally, the results might be disastrous. Designers have gone to a lot of trouble to make certain that the blades cannot be overturned accidentally, or through some breakdown of controls.

A more recent development is the production of propellers in which the blades can be turned so far that they push backward instead of pulling forward. This negative thrust is useful in maneuvering flying boats on the water where space is limited, and in cutting down the landing speed of large multi-engined land planes.

Two commonly used accessories to propellers are spinners and cuffs. A spinner is a streamlined nose-piece which fits over the hub of the propeller to reduce wind resistance at that point. It also helps to divert part of the air stream to the cylinder heads of radial engines, and adds to the streamlining of the fuselage on other planes. The cuffs are fitted over the shanks of the propeller blades, and their purpose, also, is twofold. For engineering reasons, the shank of the blade has to be made round. The cuff is a streamlined covering placed over the shank to reduce the drag its round shape would cause. It also acts as a fan, increasing the air blast required for cooling the engine. Propellers with large spinners do not require cuffs because the spinners cover the shank portion of the blades.

Jet Propulsion

The propelling of an airplane by the emission of a stream of gas at high velocity is accomplished in two ways—one by means of gas

pressure generated by free-burning fuels, the other through the burning of liquid fuel under pressure in atmospheric air. The first of these arrangements constitutes a rocket, and the fuel is composed of chemicals (solid or liquid), including oxygen which is usually in liquid form. Because the rocket carries its own oxygen supply, it can operate regardless of the presence or absence of atmospheric oxygen. It will work just as well in a vacuum as it will in the air. All rockets, however, are extravagant of fuel, and when their original charge is expended, the action stops and a fresh charge must be substituted. This system is known as rocket propulsion, even though the rocket is used to generate a jet of gas which does the actual propelling. The term jet propulsion is reserved to jets produced by jet engines.

In the jet engine liquid fuel is used which needs oxygen from the air to enable it to burn. Furthermore, in order to obtain the maximum efficiency—i.e., to get the most work out of a given amount of fuel—it is necessary to vaporize the fuel and mix it with compressed air before setting it on fire. Since oxygen is not carried, there must always be sufficient air available to provide the oxygen for complete combustion. Such an engine will not work in a vacuum, or in air so rarefied that the proper amount of oxygen is not available.

For rocket propulsion, all that is needed is a suitable container for the fuels, and an orifice out of which the expanding gases can emerge. In jet propulsion, on the other hand, an engine has to be used which will provide the power to compress the fuel mixture. But from that point on the propulsive gases will be generated continuously as long as the liquid fuel (usually kerosene) lasts. Sufficient fuel must be carried to last the required length of time, and this is quite practical because the largest part of the fuel (the oxygen) is taken from the air as needed. It does not need to be carried in the form of a liquid or gas, as in the case of rockets. Therefore, the fuel is merely the equivalent of the gasoline carried by propeller-driven planes. This, then, is the difference between rocket and jet propulsion—possibly an arbitrary distinction, but one which makes all the difference to their application to flight.

In both the jet and the rocket the propelling action is the same. The emerging high-velocity gases push the airplane along regardless of the air. The jet, as a matter of fact, would be much more efficient if there were no air to slow it down. The reason for this is that the propulsive force is due entirely to the reaction between the emerging gases and the jet chamber from which they are ejected. This reaction is explained by a simple, easily understood law of mechanics, which states that any force is always accompanied by an equal and opposite reaction. If an object is pushed with the hand, a pressure is created between the object and the hand. And the pressure on both the object and the hand will be the same—the object will push back just as hard as it is being pushed.

Pressure is created inside a rocket chamber or reaction jet. If that pressure is allowed to escape through an orifice or jet, the pressure will be concentrated in a direction parallel with (or centered on) the direction of the gas flow. In pushing the gas out, the container pushes itself forward. If a rubber balloon is blown up and suddenly released, it will shoot up in the air as the compressed air inside it is expelled through the neck. In pushing the air out, the balloon pushed itself in the opposite direction. This is reaction to an applied force. In the case of the rocket or jet, the force is maintained (or continually renewed) so that the propulsion effort is practically constant.

Both the rocket and the reaction jet are used to propel aircraft, but they are only efficient at high speeds. They are particularly suited to high altitude operation, where very high speeds are more easily attained because of the reduced density of the air. Because of control difficulties and the impracticability of long sustained flight with rocket propulsion, rockets are not likely to be used for regular passenger transport for some time to come. However, they are valuable as an auxiliary take-off device. All airplanes require considerably more power for take-off than they do for normal flight. Rockets are successfully used to provide this extra take-off power, enabling planes to carry greater loads than they otherwise would be able to do.

Current jet-propulsion systems utilize the gas turbine to provide

the large volume of air under pressure for combustion and for expansion in the jet flame pipe.

Helicopter Propulsion

The autogiro is a rotary-wing craft, just as is the helicopter, but whereas the autogiro is pulled through the air by a propeller, the helicopter is not. In the helicopter the same surfaces that provide the lift also provide the thrust—the rotors combine both functions.

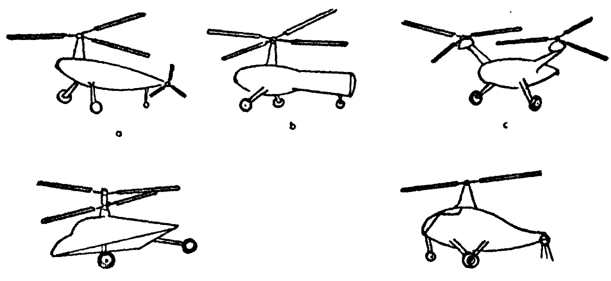


Fig. 68—Helicopter rotor arrangements: (a) 3-blade rotor with anti-torque propeller; (b) 4-blade rotor with airfoil counter-torque arrangement; (c) twin intermeshing rotors arranged laterally; (d) contra-rotating dual rotors; (e) jet type of anti-torque device

At the present stage of development, therefore, the helicopter is the only aircraft which uses a large-diameter rotor for propulsion. Furthermore, that propulsion is delivered to the craft through an approximately vertical shaft! This fact is the key to a number of the helicopter's advantages, and it is also the root of a number of problems that have not yet wholly been solved.

One of these problems is the matter of horizontal speed. Helicopters are not the fastest-flying craft! Another is complexity of control. That is why current helicopters are not suited to general use by people not fully experienced in piloting such aircraft. Even an airplane pilot has much to learn, and much to forget, the first time he takes over the controls of one of these rotary-wing craft. Pro-

pulsion of the helicopter is therefore a complex problem because it is inextricably tied up with lift.

The typical rotor blade used on most current helicopters is a continuous airfoil of wing section. It may be parallel-sided, or taper toward the tip. It is pivoted at the inner end so that it can rotate around the vertical drive shaft. It is also hinged so that it can rise and fall, within limits, as its rotating speeds increase or diminish. The rotating speed, like that of the propeller, is governed by the same laws that apply to any airfoil. This means that the tip speed must not much exceed 11 feet per second at sea level.

This limitation, and the need for a high degree of lift, have resulted in a wide variety of rotor types and arrangements. Some helicopters use two blades, some three, and some four. Others stack a one-, two-, and three-bladed rotor on top of another; some place them side by side, or fore-and-aft. These rotors vary in over-all diameter from 16 feet to 48 feet.

Because of the limit on speed of rotation, the larger the diameter the less the possible number of revolutions per minute at which it can be driven. The average rotary speed, however, seems to be well under 500 r.p.m. At this speed, a 35-foot rotor would have a tip speed of over 620 miles an hour—well within the limit of 740 miles per hour, which is the speed of sound at sea level. But allowance still has to be made for the air speed of the helicopter in flight, which is added to the speed of the air striking the rotor blades as they turn in the direction of flight.

When they are rotating horizontally, the rotors deliver nothing but lift. In order to obtain horizontal motion of the craft, the rotor has to be tilted in the direction of flight. Some of the lifting power is thereby diverted—that is to say, the lift is applied at an angle to the vertical so that there is a horizontal movement of the whole craft in the direction of lift.

This coupling of the lift with the drive, combined with the means employed to obtain horizontal motion, is responsible for the fact that the average helicopter requires twice as much horsepower as an airplane of equal load capacity. Actually, the helicopter may average 10 pounds of lift per horsepower, but 7 pounds of that

will be needed to lift the helicopter itself. There is, therefore, only 3 pounds per horsepower available as useful load.

The rotors, then, are a far different mechanism than the propeller. Besides being much greater in diameter and slower in speed, they are much more flexible in construction. Being long and thin, it is not possible to make the blades as rigid as those of a propeller.

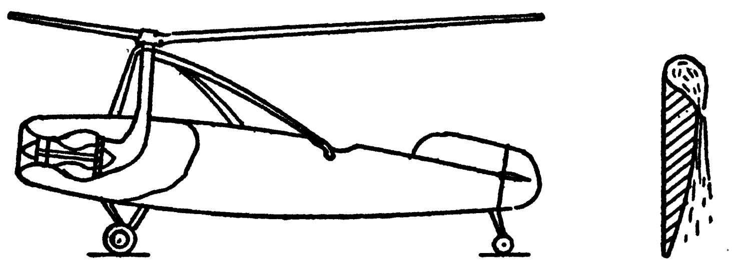


Fig. 69—The Pullin jet-propelled helicopter

Centrifugal force is counted upon to give them rigidity in flight. Since they are hinged at the root, the blades can move up and down at the tips. For this reason they respond to inequalities in the air as they turn. The flexibility and method of attachment are responsible for a great deal of the vibration from which most helicopters suffer.

When dual rotors are used, they can be made smaller for the same amount of lift, and therefore stiffer. This, however, is not the major reason for multiple rotors. Stability is the prime factor, plus efficiency introduced by the elimination of torque reaction.

When a single rotor is turned by an engine, the force applied to the rotor reacts on the engine so that the engine tends to turn in the opposite direction. This phenomenon, you will remember, was encountered in discussing propellers. In helicopters the solution for this tendency for the engine to turn the craft in the opposite direction to the rotor is the same as that employed on airplanes having two power plants. One rotor is made to turn in the opposite direction to the other, cancelling the effects of the torque reaction on the aircraft.

On some helicopters two entirely separate rotors are used, located at different parts of the fuselage. In other instances, they are mounted on concentric shafts so that they turn in opposite directions on the same center. Those helicopters which do not employ this method have a separate mechanism to counteract the torque reaction. On one type of helicopter, the engine drives a small propeller mounted vertically on one side of the tail. This propeller pulls the tail around against the reaction force which is trying to turn it in the opposite direction.

This, of course, absorbs engine power, but it does have the advantage of simplifying the directional control of the machine. If the pitch of the propeller is increased, the craft will begin to swing around the rotor axis in the direction that the rotor is turning. If the pitch is reduced, the craft will turn in the opposite direction. A number of other devices have been tried in place of the propeller, such as vertical tail vanes, or a vertical wing-shaped airfoil alongside the tail. But so far, the only really practical alternative to the propeller seems to be jet propulsion.

In jet propulsion control the idea is to squirt the exhaust gases from the engine sideways out of the tail. The amount of exhaust gas would, of course, be proportionate to the engine speed, and therefore to the rotation of the rotor. Theoretically, such an arrangement could be used with any type of engine, and auxiliary control provided by diverting part of the exhaust gases to a rear outlet as required.

Much more successful than this is the use of jet propulsion for the rotor itself. This automatically does away with any torque reaction, because the rotor is not mechanically driven by the engine. All the engine does is to provide the exhaust gases, which are ejected through nozzles along the rotor vane trailing edges at the tips. For this purpose, a gas turbine is ideal, providing a large flow of gas at the proper velocity and pressure.

As things stand, however, the torque problem is handled in a number of more or less efficient ways on current helicopters, and the horizontal motion of the craft is secured by tilting the rotor or rotors. In some cases, this effect is secured by swinging the

whole rotor in the desired direction of travel—sideways, backward, or forward. In others, a cam arrangement changes the pitch of the blades as they revolve. This is called cyclic, or azimuthal, pitch control, and it can be adjusted to take effect in any horizontal direction.

In the cyclic pitch arrangement, the angle at which the blades meet the air as they revolve is reduced at one point, and increased

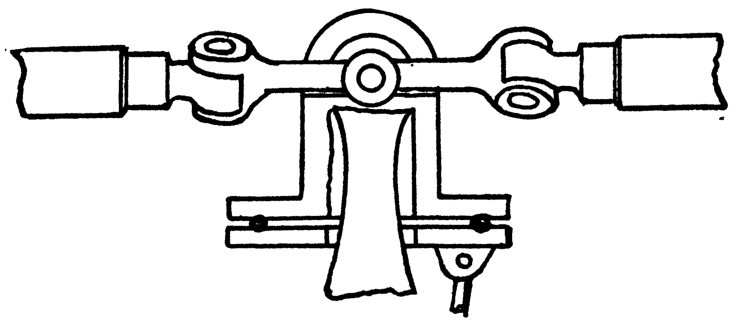


FIG. 70—Principle of the helicopter blade hinging and control

by an equal amount at a point 180 degrees further around the circle. This change of pitch is controlled, usually, by a control stick similar to that of an airplane. In one make of helicopter the tilting mechanism consists of a fixed circular plate on the rotor shaft just below the blades. Resting on this plate is another one which turns with the rotor. This upper plate is linked to the rotor blades. When the bottom plate is tilted by movement of the control stick, the upper plate tilts also, twisting the blades on their longitudinal axes.

When the control stick is in neutral position, the blades maintain their original angle throughout each revolution. The effect of moving the stick depends upon what the helicopter is doing at the time. Normally, it flies in the direction of the tilt. If the craft is flying forward when the stick is pulled back, the plate is tilted toward the rear of the craft, and the pitch of the blades is decreased as it moves to the rear and increased as it comes forward again. This causes the blades to rise in front and fall at the rear. The whole

rotor is therefore tilted backward, and the craft begins to climb.

If, on the other hand, the helicopter is hovering when this change of pitch is made, tilting the rotor backward will cause the craft to fly in that direction. If the stick is moved forward when the helicopter is flying ahead, the nose of the craft will go down. If it is hovering, it will move forward.

Similar reactions take place in connection with movements of the stick to right or left. On some helicopters the tilting of the rotor causes the fuselage to tilt also. On others the rotor shaft is tilted and the fuselage remains upright.

The rotors also have two other movements, due to the fact that they can move slightly backward and forward and up and down as they turn. This combined movement is called articulation, and it is necessary because of the varying air speeds on the rotors. When the helicopter is moving horizontally, the air speed is added to the rotating speed of the rotor blades that are moving forward. It is deducted from the blades moving backward. There is, therefore, always a difference of air speed between the blades on one side of the shaft and those on the other. That difference is equal to twice the air speed of the craft. This variation in speed alters the lift, and the articulation of the blades is designed to equalize this.

From all of this it will be gathered that, in all cases, the power utilized by the rotor to propel the craft is never more than a small proportion of the total delivered by the engine to the shaft.

CHAPTER VIII

Mechanical Brains and Telltales

IN FLYING an airplane it is very often necessary for a pilot to know a number of things he cannot observe for himself. He has to know the speed at which he is traveling through the air, the direction in which he is going, whether or not he is drifting, the altitude at which he is flying, the condition of his engine, how much fuel he has left, and so on. In flying through the overcast, in darkness, or other conditions of low visibility, the airplane might turn or bank, or rise or fall, without the pilot's knowing it, or he might even fly upside down without being aware of the fact. The only way by which he can be constantly informed of these things is by the use of instruments.

The instruments used in airplanes fall roughly into three classes—flight, navigation, and engine. The flight instruments might be called attitude instruments, since their purpose is to indicate the position of the plane in the air, whether it is level or banking, turning, climbing, or sinking. Navigation instruments are those designed to indicate the direction, altitude, drift, and speed. Engine instruments tell the engine speed, temperature of cylinders and oil, fuel and manifold pressures, etc.

FLIGHT INSTRUMENTS

The principal flight instruments are the artificial horizon, bank indicator, turn indicator, rate-of-climb indicator, and the air-speed indicator, which is also a navigation instrument.

The purpose of the artificial horizon is to show the pilot the attitude of the plane with reference to the earth's horizon when the true horizon is not visible. In flying his plane, the pilot keeps it level both sideways and fore-and-aft by watching the horizon. His wing is level with the horizon, and the nose of the plane is kept in

line with it. If he cannot see the horizon clearly, or the horizon line is broken by irregularities such as mountains, he has no plane of reference, and may find himself gliding or climbing or banking without knowing it. The artificial horizon has the effect of bringing the true horizon into the cockpit, providing the pilot with a steady

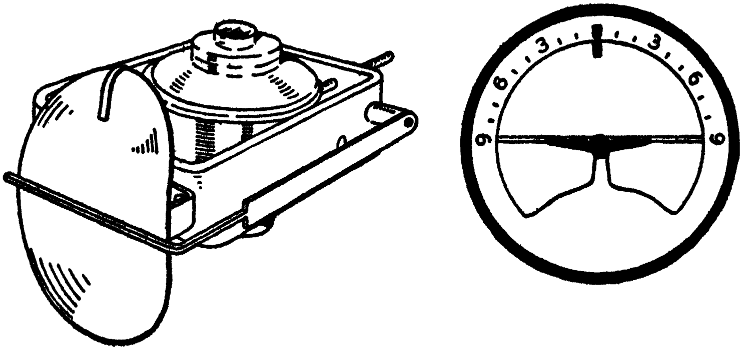


FIG. 71—Artificial horizon, operated by gyroscope

reference line which remains permanently horizontal, regardless of the movements of the plane. This artificial horizon is a line on the dial of the instrument.

The circular dial of the artificial horizon has a silhouette of a miniature airplane mounted permanently in its center. This miniature represents the airplane itself, and moves with it. Behind the wing of the miniature plane, and extending beyond it to the edges of the dial, is a white line which represents the horizon. This line is carried on a curved surface which is supported by a gyroscope so that it is always parallel with the surface of the earth, regardless of the attitude of the airplane.

When the airplane is in straight horizontal flight, the horizon line is in line with the miniature airplane. If the nose of the plane goes down, the instrument dial sinks below the artificial horizon line. If the plane goes up, the miniature plane rises above the horizon line. In looking at the instrument it appears as though the horizon line itself is moving up and down. If the airplane is banked, the small

airplane on the dial appears to bank in the same direction and to the same degree. The degree of bank is indicated by graduations around the rim of the dial. In this way, the movement of the miniature airplane with reference to the artificial horizon line duplicates every change of attitude of the airplane itself. The effect is the same as though the pilot were watching his own plane from some distance to the rear.

The gyroscope, which is the heart of the artificial horizon, is used in a number of other instruments. It consists of a heavy bronze drum, about 3 inches in diameter, and three quarters of an inch thick. Cut into the circumference of the wheel are a series of semicircular depressions or "buckets." The wheel is delicately balanced on a spindle carried in ball bearings. When a stream of air strikes the edge of the wheel, it causes the wheel to revolve at high speed. As long as it keeps turning at that high speed, the wheel will resist any effort to change the position of its axis. In the horizon the gyro wheel spins horizontally, on a vertical axis. It is supported by pivots in a gimbal ring so that it can balance itself in any direction. The whole is enclosed in an air-tight case from which air is constantly pumped. Air is allowed to enter the case through a jet, which directs it against the edge of the wheel, and keeps it turning at about 10,000 r.p.m.

The rate-of-climb indicator is a kind of altimeter, which shows the rate at which the altitude changes, either up or down. As long as the finger points to zero on the dial, the pilot knows that he is flying parallel with the surface of the earth. The instrument operates by registering the changes in atmospheric pressure: the higher the plane goes, the less will be the pressure of the air; and the lower it descends, the higher will be the pressure. These changes of pressure are made to operate the registering mechanism through the movement of a thin metal diaphragm. This diaphragm is really two diaphragms soldered together to form a capsule. This capsule, and the system of levers connecting it to the pointer, are enclosed in an air-tight case. The inside of the capsule is connected by a large-diameter tube with the atmosphere. The inside of the air-tight case is also connected with the atmosphere, but through a very fine tube

called a capillary tube. The air can therefore pass easily to the inside of the capsule, but it can pass only very slowly through the capillary tube to the outside of the capsule.

In level flight, the air pressure inside the capsule and outside it will be equal and the pointer will remain at the zero mark. But if there is any change of altitude, the pressure inside the capsule will change at once. If, for example, the plane is climbing, the pressure

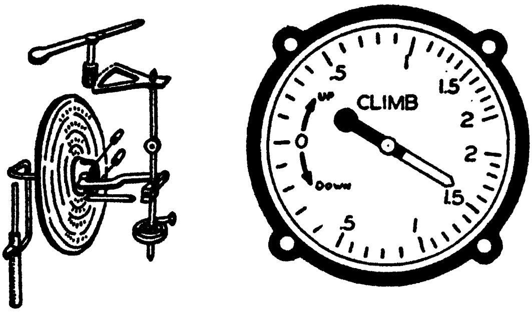


FIG. 72—Rate-of-climb indicator

inside the capsule will fall immediately. But the pressure inside the case enclosing the capsule will change slowly because of the fine tube through which the denser air must escape. If the climb is continuous, there will always be a difference of pressure between the inside and the outside of the capsule, which will register on the dial. The dial is usually graduated to read in thousands of feet per minute of climb. Often, the upper half-circle of the dial shows the ascent, and the lower half the rate of descent.

This and other air-pressure instruments are usually connected to the outside air through a device known as a pitot-static tube. This device is a combination of two elements which measure the dynamic pressure of the air through which the airplane is moving, and also the static pressure. The dynamic pressure is the pressure produced by the movement of the air; the static pressure is the pressure of the still air. Essentially, the pitot-static tube consists of two metal tubes, one inside the other. The inner tube is open at its forward end, and is mounted on the plane so that its open end projects into the air

stream. When the plane is flying, the air rushes into the open end of the tube and builds up a pressure inside it. That pressure will be proportionate to the speed of the plane through the air.

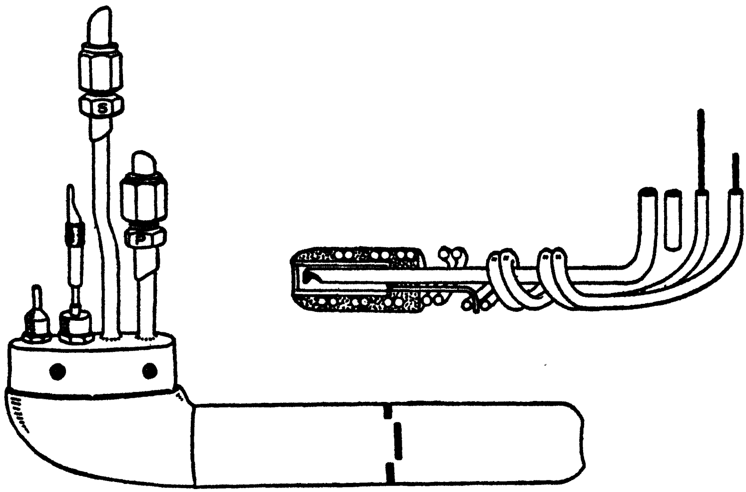


FIG. 73—Pitot-static tube, electrically heated type

The outer tube is not open at its forward end, but it has one or two slots cut in its side. These openings, therefore, are at right angles to the air stream and no air pressure is built up. The pressure of the air inside the static tube is the normal pressure of the air which slides past it, and is practically the same as it would be if the plane were standing still in the air. For the rate-of-climb indicator, only this static pressure is used.

In another flight instrument, the air-speed indicator, both the static and dynamic pressures are employed. Since the static pressure does not change with the speed of the plane, but the dynamic pressure does, the difference between the two can be used as a measure of the air speed. The air-speed indicator therefore consists of a capsule, the inside of which is connected directly to the pitot (dynamic pressure) tube. The inside of the instrument case is connected to the static tube so that the pressure there only changes with variations

in altitude. The faster the plane goes, the higher the pressure inside the capsule, and the further the hand moves around the dial, which is calibrated in miles per hour.

The speed shown by the dial is called the indicated air speed. Because of the changes in the density of the air at varying altitudes, this indication is rarely accurate. At high altitudes, for example, the air will be less dense and the indicated air speed will be less than it should be. The actual difference between the indicated air speed and the true air speed will be about 2 per cent for each thousand feet of altitude; that is, 2 per cent must be added to the dial reading.

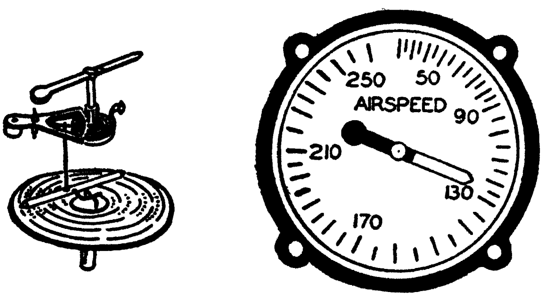


FIG. 74—Air-speed indicator

ing. At 10,000 feet, 20 per cent (10×2) would have to be added to the indicated speed. Differences in air temperature also affect the reading. Actually, there are other corrections necessary for errors in the installation and operation of the instrument. Distinctions have to be made, therefore, between the indicated air speed, corrected indicated air speed, true air speed, and ground speed.

Indicated air speed is the reading of the instrument. Corrected air speed is the reading corrected for errors in calibration, and those due to faults in the pitot-static tube installation. True air speed is the corrected indicated air speed, further corrected for density. It is the actual speed of the airplane relative to the surrounding air. Ground speed is the true air speed corrected for wind. The airplane moves in the air which, in turn, may be moving relative to the ground. If the true air speed were 80 m.p.h., with a sixty-mile wind

at right angles to the heading of the plane, the actual ground speed would be 100 m.p.h.

The air-speed indicator is a useful check on the stalling speed of the plane. The stalling speed is the speed at which the plane loses its lift and begins to fall. To fly it must move at a greater speed than that. There is also a speed above which the plane should not be dived. Some air-speed indicators, therefore, have their dials marked in color to show the safe range of flying speeds.

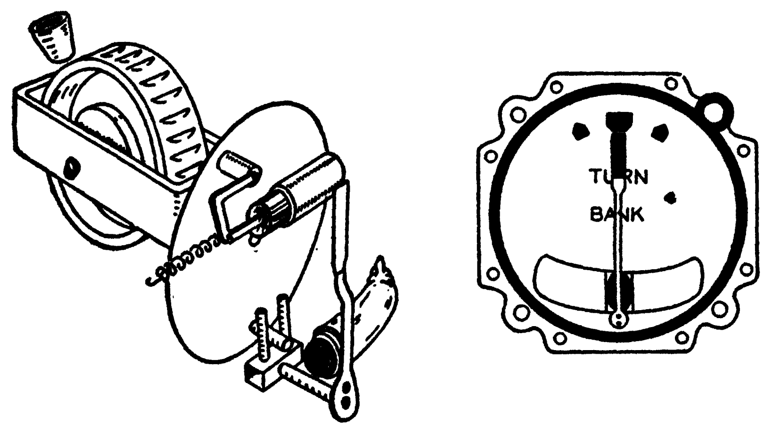


FIG. 75—Turn-and-bank indicator

The bank indicator and turn indicator are really two separate instruments, but because they are used together, they are generally incorporated in one case. The combined instrument is then known as a turn-and-bank indicator. The turn indicator operates on the same principle as the artificial horizon, the gyroscope serving to keep the indicator needle in a vertical position. In this instrument the gyro wheel revolves in a vertical plane parallel with the longitudinal axis of the airplane.

If the airplane is turned to the left, the gyro wheel will tend to maintain its original position as if continuing in a straight path. Being held in a gimbal frame, it is forced to turn with the airplane, but it will exert a force in resisting that turn. This force swings the

needle over to the left. Furthermore, the faster the turn, the greater will be the resisting force and the farther the needle will be swung over (a characteristic that is called precession). A restraining spring keeps the gimbal horizontal in relation to the airplane. During a turn, the gimbal frame rotates about its end bearings until the force of precession equals the pull of the spring. Therefore, the greater the rate of turn, the greater the movement of the gimbal frame, and consequently of the indicating pointer. From the dial the pilot can therefore read not only the direction of the turn, but the approximate rate of turn (or how fast the airplane is turning). The rate of turn, of course, takes into account the time factor, and some instruments are calibrated to show the number of degrees of turn per minute.

The bank indicator is a very simple instrument with no mechanical parts. It consists, usually, of a highly polished agate ball in a curved glass tube closed at both ends and filled with a transparent liquid. The tube is placed in the instrument case so that the lowest part is the curved center. When the airplane is in a horizontal position, at rest on the ground or flying straight, the ball will rest at the lowest part (the center). In a horizontal turn, however, a centrifugal force will tend to pull the ball to one end of the tube. If the plane is banked without turning, the ball will naturally roll to the lower end of the tube. If the bank is so great that the plane begins to sideslip, the ball will move toward the upper end of the tube.

In a banked turn the centrifugal force will tend to pull the ball to the lowest part of the curve (the center). If the bank is made at the correct angle, therefore, the ball will remain in the center of the tube. If the bank is not steep enough, the centrifugal force will overcome the force of gravity and the ball will move to the higher end of the tube. In too steep a bank it will move in the opposite direction.

The bank indicator, then, serves to show whether or not the amount of bank is sufficient for the turn or other maneuver. The purpose of the liquid is to damp the movement of the ball and prevent it from moving too violently in the tube.

The value of the bank indicator or the turn indicator might be questioned by those not familiar with the operation of an airplane. Seemingly, it should be obvious to a pilot when he is turning or banking, but this is not always so. It is a peculiar physiological fact that the varying motions in the air may confuse the senses and make it impossible for the pilot to tell whether or not he is flying straight. Particularly in recovering from a spin, or under conditions where the ground is not visible, it is often impossible to tell in which direction the plane is turning or how much it is turning. During such maneuvers the magnetic compass is of no value at all, for reasons which will be explained later.

Navigation Instruments

One of the oldest ways of determining direction is by means of the magnetic compass, and it is still one of the most useful navigating instruments for airplane use. Such compasses are subject to a number of errors, and to defects in operation, but when these are recognized and allowed for, the compass can be an accurate direction-finding tool.

The simple compass consists of a magnetic needle balanced on a pivot so that it is free to swing in any direction. One end of the needle will point North, the exact direction depending on a number of factors. The earth, as is well known, acts very much like a giant magnet, with a North and South magnetic pole. These magnetic poles are some distance away from the geographic poles, and magnetic lines of force travel through and over the earth from one magnetic pole to the other. But they do not travel in straight lines, and they do not leave or enter the earth at the same point.

Because of this distortion of the magnetic field, the needle of a compass rarely points directly to the magnetic poles. It lines itself up with the local magnetic field. The difference between the direction from a given point to the geographic pole, and the line along which the magnetic needle points, is known as the variation. Maps are available which show the variation at a great many points all over the surface of the globe.

The aircraft magnetic compass usually consists of two cobalt steel magnets, parallel, but spaced so that there is one on each side of the pivot point. They are mounted on a float resting on the pivot, and the complete assembly is submerged in a liquid. The float reduces the weight of the magnets on the pivot. The most commonly used type of magnetic compass is mounted above or in the instrument panel so that the pilot must look at it from one side instead of the top. This means that the compass card, which is graduated into 360 degrees, has to be vertical. This vertical strip is attached around the

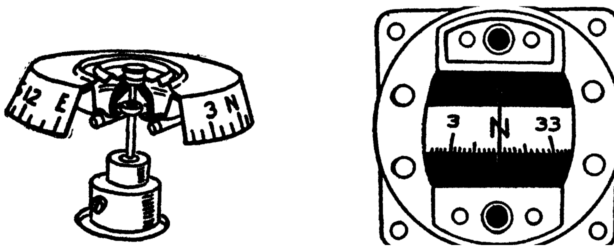


FIG. 76—Magnetic compass

edge of the horizontal float. The pilot sees a portion of it through a glass lens, across the middle of which is a thin line or wire, called the lubber line, which marks the direction in which the plane is going.

Since the pilot sits behind the compass, when he is going North he will be looking at the South end of the needle. Therefore, the card and all the markings have to be reversed so that it will read N when he is going North. Although the card is graduated in 360 degrees, the letters N, E, S, and W are substituted for 0 degrees, 90, 180 and 270 degrees. Also, the final zero is omitted from each reading in order that the numerals can be made larger and clearer.

This type of compass has one serious defect—a tendency to keep on swinging or oscillating after each change of direction is made. It takes so long for the card to become steady again that the pilot may turn too much or too little. For ordinary purposes this may not be very serious, but such a compass is not suitable for navigation

purposes. The navigating type of compass is a top-reading type, called the aperiodic compass. It gets its name from the fact that it does not oscillate back and forth on either side of the proper heading. Instead, it returns to its true heading slowly and does not swing beyond it. Such compasses may be mounted between the pilot's knees or on a shelf close beside him. Where a navigator is carried, the compass will, of course, be carried in the navigator's compartment. The readings on the aperiodic compass card do not have to be reversed because they can be read directly.

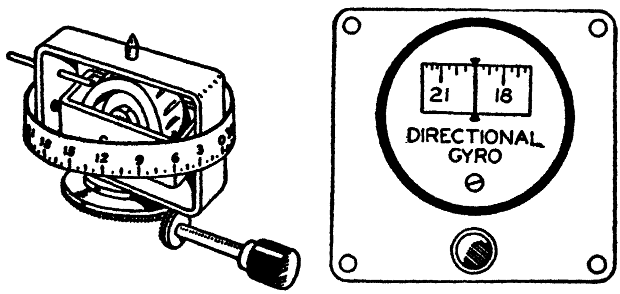


FIG. 77—Directional gyro

In mounting any type of compass on an airplane, the compass has to be carefully checked for "deviation" due to the attraction of metals around it, or the influence of electric currents. This is done in a variety of ways according to the problem involved. Sometimes other magnets are added, or pieces of iron placed so as to counteract the unwanted attraction. Such corrections for deviation should not be confused with corrections for variation, which will be discussed in the chapter on navigation.

A device intended to supplement the magnetic compass is the directional gyro. This is really a mechanical compass, which gives a positive indication at all times. It tells the pilot the exact direction in which the plane is flying, as well as the degree of turn. The basis of this instrument is a gyroscope wheel spinning on a horizontal axis, supported in a gimbal ring. The vertical gimbal ring, which is free to turn about its vertical axis, carries a circular compass card.

This card can be seen through a square opening in the front of the instrument case which has a lubber line across it.

Because the spinning gyro wheel remains rigid, the gimbal ring and the card also remain in a fixed position. The airplane and the instrument case move around them. A caging knob is used to set the gyro so that it coincides with the magnetic compass, and to reset it at periodic intervals. The rotor is kept upright by the use of two air jets which turn the wheel. If the rotor tilts, the air from the jet on one side strikes against the rim instead of against the buckets. The

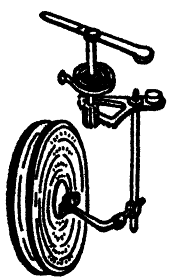


FIG. 78—Altimeter

air from the other jet strikes the side of the buckets, pushing it back into its upright position.

The directional gyro is read just the same as a magnetic compass, but it must occasionally be reset to make up for creep of the gyro wheel.

The height at which a plane is flying is measured by an instrument called an altimeter. The altimeter works by measuring the pressure of the air. At sea level, under normal conditions, that pressure would be 14.7 pounds to the square inch. At that point, the altimeter would register zero. From that point upward, the greater the altitude the less would be the air pressure, and the further the instrument needle would move over the dial calibrated in feet or hundreds of feet. The altimeter is therefore nothing more or less than an aneroid barometer with a special indicating scale.

The altimeter mechanism consists of a diaphragm capsule from

which much of the air has been removed. Since there is very little air pressure inside the capsule, the pressure of the air outside it tends to bend the diaphragm inward. As the outside air pressure grows less, the capsule expands. Attached to the capsule is a lever and gear arrangement which multiplies the diaphragm movement and uses it to turn the indicator needle over a dial.

The whole mechanism is mounted inside a protective case, and the atmospheric pressure is brought to the inside of the case by means of a tube terminating in a static head. There are two general types of altimeter—the standard and the sensitive. The difference between them is their degree of sensitivity to slight changes of air pressure. The standard type of altimeter has a single dial pointer which makes one revolution for each 5,000, 10,000, or 20,000 feet of altitude. The sensitive instrument, on the other hand, generally has more than one pointer. Usually, a large pointer makes one revolution for each 1,000 feet, with a smaller hand turning one revolution for 10,000 feet. In some instances, there is a third hand which revolves once in 40,000 feet.

Altimeters are calibrated according to what is known as the standard atmosphere. This takes the standard conditions at sea level as being a pressure of 29.92 inches of mercury (in a mercury barometer), and a temperature of 59 degrees F. On this basis, a pressure-altitude table is established which gives the normal pressures and temperatures at various altitudes. At 10,000 feet, for example, the standard pressure would be 20.58 inches of mercury (usually written "in. Hg."), and the temperature 23 degrees F. Air pressures and temperatures unfortunately vary not only from hour to hour, but according to the locality. That is why altimeters must constantly be checked and reset.

Resetting usually means simply the turning of a knob on the instrument case, and barometric readings are given at frequent intervals by Weather Bureau broadcasts, or they can be obtained from airports. Many airplanes carry a thermometer which reads the temperature of the outside air. If the temperature is higher than it should be for the altitude, the actual altitude of the airplane will be greater than is shown on the altimeter. The correction for tempera-

ture error is 2 degrees of the indicated altitude for every 10 degrees F. that the temperature differs from the standard.

In flying in a cross wind the airplane will not be moving in exactly the same direction as that in which its nose is pointing. While it is moving forward it will also be moving sideways, and if a navigator is to learn his position, he must know exactly how far the plane is drifting. To help him determine this he uses an instrument called a drift indicator or a drift sight.

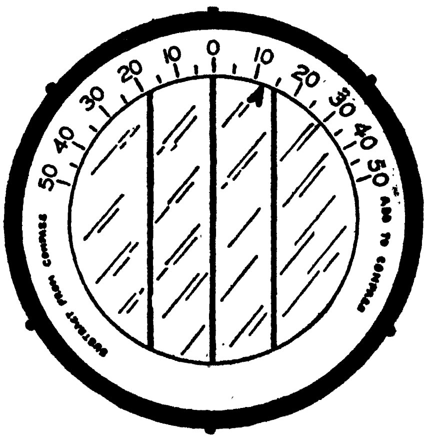


Fig. 79—Drift meter

There are several common types of drift indicators, all of which measure the angle between the direction in which the plane is pointing and the direction in which it is moving. This is called the drift angle. The simplest type is a drift meter, consisting of a lens which is installed in the floor of the airplane. The drift meter is composed of a ground-glass image screen and a compound lens. It is mounted so that objects passing under the plane are reflected in the screen. Above the screen are three parallel grid lines attached to a rotatable frame, around which is a graduated scale showing degrees of angle right or left.

To determine the drift angle, the grid lines are rotated until the path of the objects passing across the screen is parallel to them. The

angle is read from the scale, and is then added to or deducted from the compass heading, depending on which side of the course is the windward one.

In making turns as well as in calculating distances, an accurate timepiece is essential. Airplane clocks are specially designed for the severe operating conditions they encounter. Some of them are equipped with sweep second hands, and some incorporate stop-watch mechanisms for timing turns, dives, climbs, etc.

Instruments that indicate the rotating speed of an engine are called tachometers, and they may be of the mechanical, electrical,

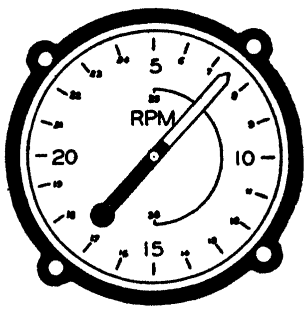


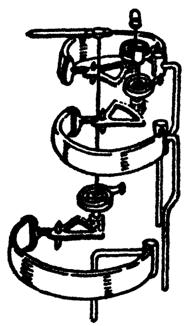
FIG. 80—Tachometer dial

or magnetic type. The mechanical type is also called the centrifugal type because it utilizes the centrifugal force developed by revolving weights.

In the centrifugal-type tachometer, the weight mechanism is mounted on a shaft which is driven by a flexible coupling direct from the engine. As the weight arms fly outward with the spinning force, they slide a collar along the shaft. This, in turn, moves a lever and gears which turn the dial pointer. The pointer is kept steady by a hairspring on its shaft. The faster the drive shaft revolves, the wider will fly the weights, and the farther the pointer will move over the dial which is calibrated in revolutions per minute.

In the electric tachometer, a pair of electric wires take the place of the flexible drive shaft. A direct-current generator is mounted on the engine, and a synchronous motor is installed in the instrument

case. The motor is "synchronous" because it runs at the same speed as the generator. Attached to the shaft of the motor is a magnet which revolves with it. This magnet turns inside an iron drum. The magnetism makes the drum want to turn with the magnet, but a hairspring on the drum shaft checks it. However, the magnet does pull the drum with a steady, even pressure, according to the speed at which it turns. Variations in the engine speed produce variations in the speed of the electric motor, and therefore the strength of the pull of the magnet on the drum. The drum is geared to the dial needle which registers the pull in r.p.m.



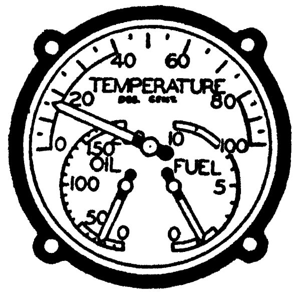


Fig. 81—Engine gauge, consisting of oil, fuel and cylinder temperature gauges

The mechanism of the magnetic tachometer is practically the same as that of the electric tachometer, except that there is no generator or motor. The drive is by flexible shaft, as in the case of the mechanical type, but the registering is done by a rotating magnet's attraction for a metal drum.

Temperature gauges are an important group of engine instruments. They are used to indicate the temperature of cylinder heads, the engine oil, the coolant liquid, and the carburetor intake air. For measuring oil and cooling-liquid temperatures, a vapor-pressure type of gauge is commonly used, because the temperatures are generally below the boiling point of water.

The vapor-pressure type of gauge consists of a hollow bulb con-

taining a fluid, and a capillary tube connecting the bulb with a Bourdon tube. The Bourdon tube is a curved section of flat and flexible brass tubing, closed at one end. Any pressure applied to the inside of it will tend to straighten it out. The movement of the closed end during this straightening can be made to move a pointer over a dial. In the vapor-pressure gauge, the bulb is inserted in the liquid, the temperature of which is to be measured. The heat causes the fluid and its vapor to expand, producing pressure in the Bourdon tube. The movement of the Bourdon tube rotates the pointer over a dial which is calibrated in degrees centigrade.

For measuring cylinder-head temperatures, up to 600 degrees F., a thermocouple type of thermometer is often used. The basis of this instrument is the thermocouple, a pair of small plates made of dissimilar metals brought together at one end. When the contacting end is heated, an electric potential is produced (voltage is generated), and this voltage is in proportion to the difference in temperatures between the hot ends and the cold ends of the thermocouple. The complete instrument therefore consists of this thermocouple, together with a meter for measuring the voltage.

The thermocouple units are made in a variety of ways, a common form being what is known as the blind-rivet type. This unit is screwed, or hammered like a rivet, into a special hole drilled in the engine cylinder. Another form is the gasket type, which fits like a washer under the head of a screw or even of a spark plug. It is standard practice to apply several such thermocouples to an engine, connecting them all to a selector switch. This permits the use of one indicator dial on the instrument panel to serve several units, each of which can be switched in at will. The recording instrument is actually a voltmeter, but the dial is made to read in degrees of temperature.

Since the voltage generated by this type of indicator is very small, it is not suitable for measuring lower temperatures which would generate still lower voltages. Another type of electrical unit is therefore sometimes used in place of the vapor-pressure indicator for measuring the temperatures of oil, air, or cooling liquids. This is the electric resistance-type thermometer. The principle on which

it works is that metallic wires have a higher electrical resistance when they are hot than when they are cold. In these electric resistance thermometers, the resistance of the heated element is measured very accurately by a device known as a Wheatstone Bridge. The bridge, which is described in most elementary physics textbooks, is a balanced network of resistances. Voltage is supplied to it from a battery or generator, and any change of resistance in the circuit connected to the heated wire will cause a current to flow and to be registered on the dial of a meter.

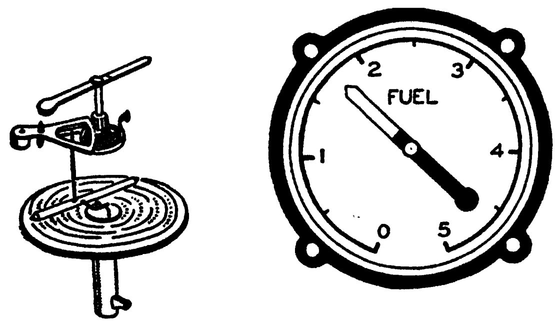


FIG. 82—Fuel pressure gauge

The resistance wire which forms the unit to be heated by the air or liquid is wound on an insulating rod and enclosed in a protective metal case which readily conducts heat to it. This unit is called the resistance bulb, and is connected by a pair of wires to the meter which contains the rest of the apparatus.

Pressure gauges use either a Bourdon tube or an aneroid capsule to provide the mechanical motion to operate the dial pointer. For measuring oil pressure the Bourdon type is used, the tube being connected directly with the oil line. Oil therefore enters the Bourdon tube, and its pressure straightens the tube which operates the indicating pointer. The dial over which the pointer moves records the movement in pounds per square inch.

For measuring the pressure in an engine intake manifold the aneroid type gauge is used. The aneroid unit consists of two strong

capsules or cells, from which most of the air has been removed. These are housed in an air-tight case which is connected by a tube to the engine manifold. Any change in the manifold pressure therefore compresses or expands the capsules, and this movement operates the indicating pointer over the dial. The dial is generally calibrated in inches of mercury, ranging from 10 to 50 inches, 30 inches being standard sea-level atmospheric pressure.

Another important thing for the pilot to know at all times is the amount of gasoline he has in his tanks. For this purpose he may

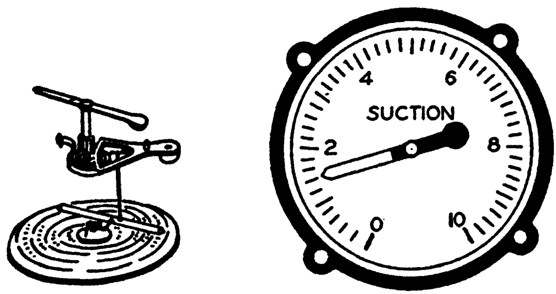


FIG. 83—Suction gauge for de-icer systems, etc.

use any one of three types of gauges—the sight gauge, the hydrostatic gauge, or the electric gauge.

The sight gauge is, as its name implies, a direct-reading level indicator. It is used only on light planes. It consists of a transparent tube, inside which a colored ball moves up and down according to the changes in the fuel level in the tank. The ball is supported by a wire, which terminates in a float resting on the surface of the fuel. The more fuel there is in the tank, the higher the colored ball rises. The tube is usually graduated in gallons. An inverted arrangement of this system can be used on airplanes that have the tank in the center section of a parasol wing. The gauge then hangs downward from the bottom of the tank so that it will be in view of the pilot during flight.

The fact that the pressure of a liquid is proportional to its depth makes possible the hydrostatic type of fuel quantity gauge. With

this type of gauge a bell-shaped metal cell rests just clear of the bottom of the fuel tank. Air is pumped into the cell by means of a hand pump and displaces the gasoline inside it. The difference between the pressure of the air in the cell and the pressure of the air

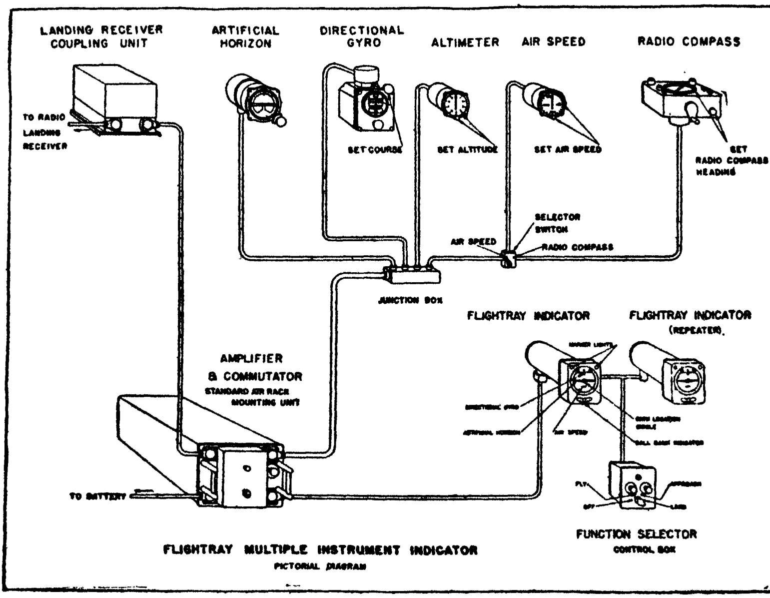


FIG. 84—A modern navigation instrument group

above the fuel in the tank operates an aneroid capsule. The capsule, in turn, operates a pointer over the gauge dial, which is calibrated in gallons.

The electric gauge (or liquidometer) has the advantages of light weight and the elimination of all tube lines between the tank and the instrument case. It is also very simple in operation. In the fuel tank is a float on the end of a lever arm. The movement of this float turns the contact arm of a rheostat (a variable resistor). This rheostat controls the flow of an electric current from a battery to the gasoline gauge which is actually a voltmeter. The more gasoline there is in the tank, the less resistance there is in the circuit and the

higher the voltage applied to the gauge, which is calibrated to read in gallons.

Many more instruments than the ones described are used on some large airplanes. Indicators are used to show the positions of the landing gear and wing flaps, and fuel analyzers indicate the proportions of fuel and air in the mixture. On multi-cylinder aircraft, other instruments called synchronizer indicators show whether or not all engines are revolving at the same speed, and still other dials may show the actual horsepower developed by each engine.

These and some other instruments are made possible by the use of remote indicating systems. Such systems comprise a pair of synchronous electric motors of a special type. If the armature of one of these motors is turned, the armature of the other will turn exactly the same amount. One of the motors is located near the source of measurement and is called the transmitter. The other motor, equipped with a suitable dial and pointer, is mounted in the instrument panel and is called the indicator. A pair of wires connect the indicator with the transmitter, and with some source of electric current. This eliminates the need for rods, cables, or tubes, and the distances from one to the other, or their points of location, are of no importance. By means of a selector switch, one indicator can be used to record the readings of several transmitting units on two or more engines, thus reducing weight and conserving space.

CHAPTER IX

How Airplanes Are Flown

IT IS EASY to fly an airplane—when once you know how! The controls are simple and require little effort to operate, but to use them correctly in all kinds of maneuvers calls for a great deal of knowledge and no little skill. A wing is not like a wheel nor the hull of a sailboat, and driving it along a three-dimensional course through the air necessitates a coördination of controls that no other vehicle demands. Furthermore, the airplane is a contrary contraption. You pull back on the stick to go up, but if you pull back too far, you quickly come down again. In landing, you pull back the stick to set the plane down, and when you are falling and likely to crash, the only way to save yourself is to dive toward the ground.

These and a hundred other rules that are contrary to common sense and instinct make flying a subject that has to be learned by first forgetting any preconceived ideas on the subject, and replacing instinctive reactions with trained reflexes. There is no such thing as a "natural-born flyer." Some people learn to fly more readily than others, just as some have a natural interest in other accomplishments. But for most people piloting an airplane means training, perseverance, and plenty of practice.

In spite of the large variety of airplanes manufactured, most of them are basically the same, and the controls are standardized. While some have a control wheel and others have a plain stick, the movements are the same. The wheel moves backward and forward just as the stick does, and turning the wheel to right or left is exactly the same as moving the stick in the same direction.

In reviewing the various control operations involved in flying a plane, it will be assumed that the airplane is a cabin type of light trainer, with a stick and rudder-pedal control. It will be a parasol-wing type and will be equipped with means of regulating the stabilizer from the cockpit while in flight. A great many modern

planes have this useful device which changes the angle of attack of the stabilizer so that the air pressure on the tail can be made to balance the plane longitudinally. Its purpose will become clear in due course.

The airplane, before it can be flown, will have been government-inspected, and certified as airworthy. It will have a license card in

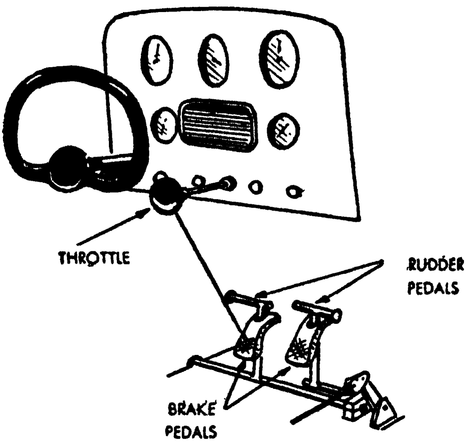


FIG. 85—Typical light airplane control arrangement

the cabin, and on the rudder and fin will be painted the registration number, preceded by two letters. The first of these letters will be N, which means that it is of American registration. The second letter will be C, which stands for commercial. This means that it can be used to carry passengers (including flying students) or goods.

Airplanes marked with an N only have not yet proved themselves airworthy. Those with the prefix NX are experimental types, and NR means that they are licensed only for special work such as crop dusting and advertising.

In the cabin, then, beside the stick and rudder pedals, there is an adjustable throttle knob. Pushing the knob forward makes the engine go faster; pulling it back slows the engine down. In this particular case, the throttle is on the left-hand wall of the cabin,

with the stabilizer adjusting crank just below it. In other cases, it may stick straight out of the instrument panel, but, always, pushing forward means more engine speed.

The instruments are, from left to right: a tachometer, oil temperature gauge, air-speed indicator, compass, oil pressure gauge, altimeter. At the bottom of the panel is the ignition switch (often located below the throttle), and close by is the primer pump and gasoline shut-off switch. Behind the panel is the gasoline tank, with a sight gauge sticking up out of the top. Now let us see exactly how the airplane is flown.

As soon as the pilot takes his seat, he fastens his safety belt, then checks the action of the controls by moving the stick around and pushing the rudder pedals. Because this plane has no self-starter, it is necessary for a mechanic to "swing the prop." Before this is done, the landing wheels are firmly chocked with large blocks of wood shaped to fit the wheels, the plane having no brakes. The pilot now makes sure that the throttle is closed and the ignition switch off.

As the mechanic prepares to turn the propeller, the pilot injects a little fuel into the engine cylinders by means of the primer pump. Now the mechanic turns the propeller a few times to make sure that the cylinders are filled with mixture. He calls to the pilot, "Contact!" The pilot switches on the ignition, answering "Contact!" as he does so. With his right hand on the stick and his left hand on the throttle, the pilot watches as the mechanic jerks the propeller blade sharply down. The engine barks into life, and the pilot opens the throttle until it runs smoothly at moderate speed.

No take-off is possible, or advisable, until the engine is warm enough to run smoothly at full throttle without spitting. The oil must be warm enough to circulate freely, and the engine warm enough to properly vaporize the fuel. In a few minutes, the pilot "revs up" the engine and casts an eye over the gauges. If everything is all right, he is ready to take off. A glance at the wind sock or wind tee tells him which runway he must use so as to take off into the wind.

With the engine idling over, the pilot signals to the mechanic

to remove the wheel chocks. He then taxis to the end of the runway, keeping a sharp lookout for other planes on the ground and in the air. Since the tail wheel is on the ground, the nose of the plane is high in the air and the pilot cannot see the ground directly in front of him. In taxying he pursues a zigzag course so as to make certain that there is no obstruction ahead. His hand is on the throttle and the speed is slow, with the control stick in neutral position.

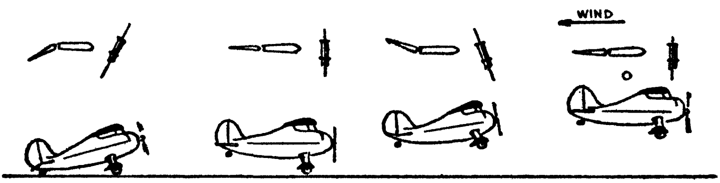


FIG. 86—Take-off positions of elevators and control stick

The only control used is the rudder, and this must be swung far over to make the plane turn because of the low speed.

And now, facing into the wind at the end of the runway, our pilot is ready to take off. He advances the throttle gently until the engine is running fast and smooth, then, with one quick, firm motion, pushes it open wide. Already the plane has begun to move, and the pilot fixes his eyes on some object straight ahead so that he can tell when the plane begins to swing to one side or the other.

As the plane starts to roll, the pilot carefully eases the stick forward until the tail lifts and the plane is level, running along on its two wheels. When it reaches that position the stick is returned to neutral. Gradually the speed increases, and the controls become more responsive. Presently, flying speed is reached, as the pilot can tell by the change in the feel of the controls. The plane now feels as if it wanted to fly, and as the pilot eases back on the stick, the wheels begin to leave the ground.

Now the airplane is flying, but the pilot keeps the nose level to give it a chance to pick up more speed. Then he gradually lifts the nose again and climbs for altitude. Clearing all obstructions, he keeps on in a climbing turn to the desired altitude and direction.

Flying level, the pilot checks the attitude of the plane by a glance

at the wing tips to see if they are parallel to the horizon. Looking ahead, he sees where the nose of the plane is in relation to the horizon. The point at which the horizon line will cut the engine cowling will vary with the airplane, but in level flight the center of the propeller will seem to be pointing directly toward it. Now if the pilot releases the controls, the plane should keep on flying level. If it tends to climb or dive at cruising speed, it is not properly balanced and that must be corrected by adjusting the stabilizer control.

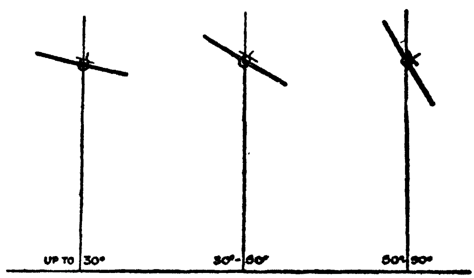


FIG. 87—Gentle, medium, and steep banks

Now the pilot is ready to make a left turn. He applies a little left rudder, and at the same time moves the stick slightly to the left. At once the left wing goes down and the nose of the plane swings along the horizon to the left. When the proper degree of bank is reached, he returns the stick to neutral. If the nose of the plane begins to drop below the horizon, he pulls the stick gently back until that is corrected and the altitude maintained.

In any turn the wing will try to bank itself more steeply. The reason for this is that the high wing has to travel a greater distance than the low side, which means that it travels at a higher speed. Since the amount of lift is dependent on the speed, the high wing will have greater lift than the low one. This is corrected by holding the stick in the neutral position, and using the rudder only to correct any yawing movements of the wing tips.

To return the airplane to straight flight from this bank, the pilot tilts it to the right and applies enough rudder to bring it onto its course again. Since he is now facing in the direction from which he

came, he has made a 180-degree turn. With a similar turn beyond the far end of the landing field, he will be in a position to make a landing into the wind. This turn is called the approach turn, and it has to be made so that, as the plane comes out of it, it will be headed straight for the runway. According to air traffic rules, this straight approach must be at least 1,000 feet long.

In coming out of the turn, the pilot drops the nose of the plane slightly by easing forward on the stick and pulling back the throttle

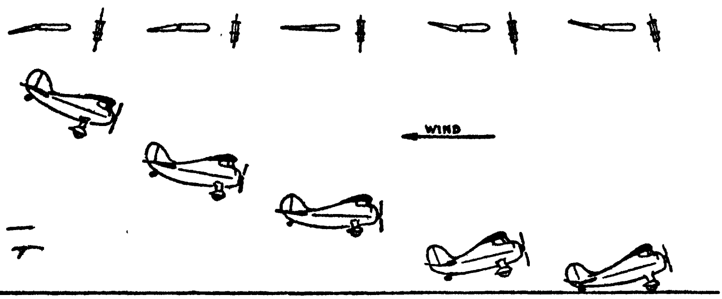


FIG. 88—Landing positions of elevators and control stick

just a little. As the speed decreases, the nose of the plane drops a little more. Now the pilot decides that this is his best gliding angle for the distance he has to cover, and he holds the plane in that position with the elevators while pulling the throttle back all the way. In a long glide such as this, the pilot keeps the engine warm and ready for instant action by opening and closing the throttle a number of times.

By the feel of the control stick and the position of the plane's nose relative to the horizon, the pilot judges the proper approach speed. Too steep a glide will give him too much speed, and too flat a glide will slow the plane so much that the controls will not be properly effective. Now, with the plane just a few feet above ground, the pilot eases back on the stick, bringing the nose of the plane up to the horizon. By leveling off in this manner the speed is reduced for the actual landing. Pulling the stick back a little more, he lifts the nose and drops the tail as the wheels almost skim the runway.

Back comes the stick a little more, and the three wheels hit the ground together—a three-point landing. The pilot keeps the stick back and holds the plane straight along the runway until it comes to a full stop.

This landing was good because the pilot's judgment was good. He brought the plane as close to the ground as he could without touching, and the plane landed itself as its nose came up into stall position. If he had held it too high off the ground, it would have dropped hard when it lost flying speed and made a pancake landing. If he had come too close, the wheels would have struck the ground while the plane still had flying speed and it would have bounced back into the air. Then the only thing to do would be to slam the throttle open wide until control was regained, close the throttle and glide for another landing—if there was room enough. Otherwise, he would have had to start all over again by circling the field.

If the pilot coming in for a landing suddenly finds he is too high, he can lose altitude quickly by making either a sideslip or a forward slip. The sideslip is executed by pulling the plane's nose above the horizon, banking and applying top rudder (turning the rudder to the high side). The stick is then eased forward just enough to prevent the plane from turning.

In the sideslip, the pilot keeps the nose of the plane high to prevent it gaining speed in the slip. Otherwise it is very similar to the sideslip, but the loss of altitude is more gradual. The wing is banked about 30 degrees, and the opposite rudder applied. This is done first to one side then the other, care being taken to make the changes smoothly and evenly so that there is no loss of control.

At the beginning of this chapter, we mentioned that if the stick is pulled back the plane will climb, but that if it is pulled back too far the plane will fall. The reason that it falls is that the wing's angle of attack has been increased to a point where the air stream breaks away from its upper surface and lift is lost. This condition is known as a stall. Stalls can occur in a glide or turn as well as in a climb, or in any maneuver in which flying speed is lost.

Although most modern light planes are so designed that it is dif-

ficult to stall them, it is important for the pilot to know about stalls in order to be able to recognize one when he sees it. Better still, he should be able to recognize an impending stall before it happens. Therefore, practice stalls are a useful part of a pilot's training. The

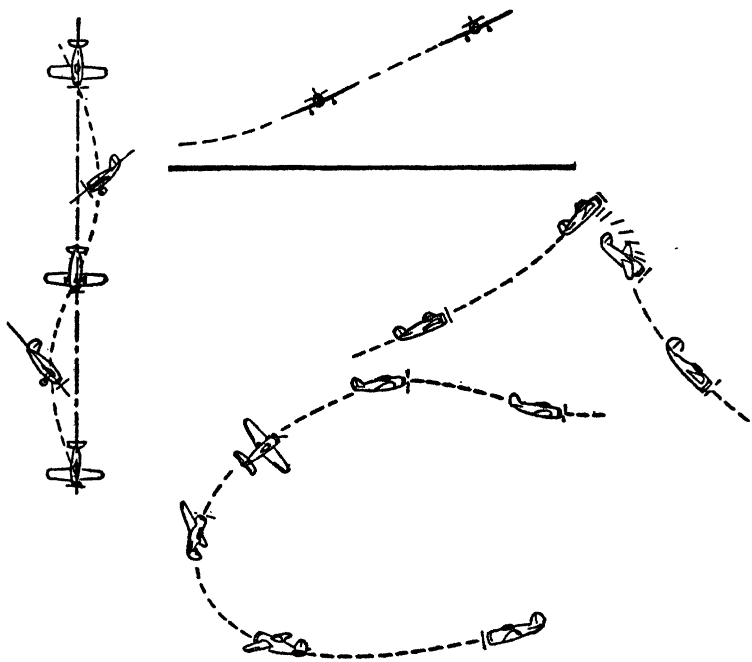


FIG. 89—Center above: A sideslip; Left: A spin; Right: A stall; Below: A climbing turn

first essential in practicing stalls is to gain plenty of altitude, say 3,000 or 4,000 feet.

With the plane flying along level at cruising speed, the throttle is suddenly closed. The pilot pulls back slowly on the stick until it is as far back as it will go. Naturally, the nose of the plane goes up, but since there is no spinning propeller to pull it, it does not go far. Immediately, the controls become ineffective and "sloppy." In trying to climb, the plane loses speed and the nose tries to go down.

This is the point of stall. What the pilot does next depends on whether or not the stall is dangerous.

Normally, when the nose of the plane goes down, the way to get it up is to pull back on the stick. But not in a stall. The problem now is to regain flying speed, and that can only be done by letting the nose drop. To hasten this process, the pilot pushes the stick forward. As the speed increases, the plane can be leveled off in normal flight. Recovery has been made from a power-off stall. The plane behaves in a similar manner if the stall is made with the engine power on, but the action is much more abrupt. Recovery also is more rapid, but in the stall there is usually a strong tendency for the plane to fall off on one wing. If that tendency is not checked, the plane will go into a spin.

In straight flight the low wing would be brought up by moving the stick to the high side. In a stall that would merely make matters worse; the thing to do is to level the plane by using the opposite rudder. That is, if the right wing is low, the rudder is turned to the left.

In days gone by, a tailspin usually meant trouble for the pilot. Not much was known then about spins or how to build an airplane that was spin-proof. Nowadays, it is very difficult to make most planes spin at all, and manufacturers are not allowed to sell one that will not bring itself out of a spin in short order. In a spin the airplane plunges toward the ground nose first, whirling as it goes. The tail turns around in a large circle and the nose turns around in a small one.

To put the plane into a spin, our pilot takes it to a safe altitude and stalls it, either with power on or power off. As the nose begins to go down, he gives it full rudder to the side he wants the spin to start, keeping the stick pulled back as far as it will go. Now, as the nose points steeply down, the plane begins to turn, the tail making one spiral while the nose makes a smaller one. This spin will continue as long as the controls are held in the position which started the spin. To come out of the spin, the pilot merely returns the controls to neutral, thus putting the plane in a dive. By easing back on the stick, he then brings the plane back to level flight, and opens

the throttle to cruising speed. If the power was on during the spin, the first step in recovery would be to close the throttle. That is the only difference between the power-off and power-on spins.

The stall is the basis of another maneuver much used in acrobatic and combat flying, the stall turn. It enables the pilot to lose height quickly and to turn at the same time. The stall is executed as usual by pulling the nose of the plane sharply upward. As the nose begins to drop, he gives it full rudder, right or left, according to the way he wishes to turn. As the plane turns on its wing tip, the stick is returned to neutral, the throttle is closed, and the rudder neutralized. This leaves the plane in a steep dive, facing in the required direction. To regain level flight, all that is necessary is to pull back on the stick and open the throttle to cruising position.

In addition to the stall turn and the medium turn described earlier, there are steep turns, gliding turns, and climbing turns, in all of which the controls are handled somewhat differently. In the steep turn, the wing is almost vertical, and extra power is necessary to maintain sufficient speed to avoid sideslipping. The turn is begun in the same way as a medium turn, but the stick is held over till the plane has rolled almost on its side.

In this position the rudder is practically horizontal, and the elevators almost vertical. Any movement of the rudder now will raise or lower the nose of the plane, and the elevators will act as a rudder in turning the plane faster or slower. Therefore, the rudder is now used to maintain the nose in the horizontal position and the elevators to control the degree of turn.

Recovery from a steep turn is made by moving the stick sideways, to the left if a right turn is being made, and to the right if it is a left turn. The rudder is allowed to return to neutral and the throttle is eased back. The stick comes back to neutral as the wing comes level. Such a turn is used only in racing or combat, the normal shallow or medium turn rarely exceeding 30 degrees from the horizontal.

In a turn made while the plane is in a glide, the engine is idling and progression is slow and smooth, and the turn is shallow. The plane therefore has a tendency to fly with its wing level and its nose straight. In making such a turn the pilot returns the stick to neutral,

and very little movement in the opposite direction is needed to right it. The important thing in a gliding turn is to maintain speed and therefore lift. In all turns there is a loss of speed and lift. In a gliding turn this is compensated for by keeping the nose a little lower than in the straight glide. A plane will stall and spin out of a glide just as well as it will out of a climb.

When the plane is making a climbing turn, most of the engine's power is being used in the climb and little extra is left for the turn. Such turns must therefore be slow, and the throttle must be opened further before starting one. The rate of climb should be somewhat less than usual in a straight climb, steadily maintained. With a steady rate of turn and angle of bank, the turn will then be smooth throughout.

In the field of aerial acrobatics there are a number of maneuvers that are thrilling to execute and beautiful to watch. There is the

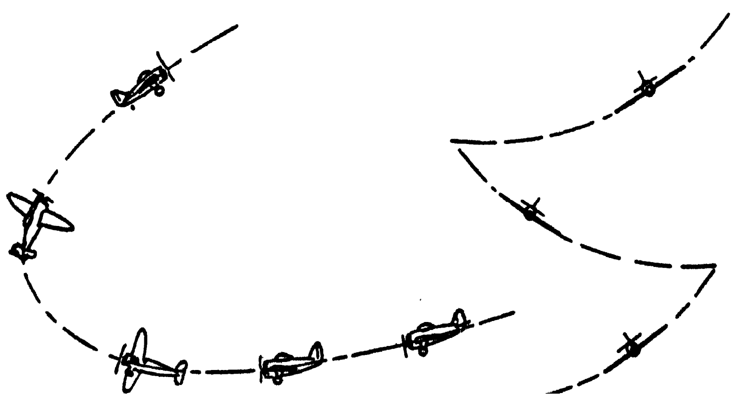


Fig. 90—Left: A chandelle; Right: Falling leaf

falling leaf, the chandelle, the Cuban eight, the Immelmann, and a variety of loops and rolls. All of these are useful in teaching the pilot coördination in handling the controls, and with a modern airplane (and plenty of altitude) most of them are perfectly safe, unless too much diving speed is acquired before attempting recovery and level flight.

In the falling leaf the objective is to make the plane drop first one wing, then the other, so that the plane swings from side to side as it descends. At the same time, the nose of the plane must be kept pointed in one direction, and that is the most difficult part of the maneuver. The first essential, therefore, is to select some landmark ahead toward which the plane can be pointed throughout.

The first part of the maneuver is practically a power stall. The stabilizer is set to the tail-heavy position and the throttle gently closed. The stick is eased back slowly, as the speed decreases, so that the nose is held just above the horizon. When the stick is hard back, slight pressure on the rudder will start one side of the wing to drop. If the rudder is moved to the right, the right wing will fall. If it is moved to the left, the left wing will drop.

The instant the wing starts to move down, light opposite rudder is applied. The rudder is held over until the wing is almost level again. The rudder is then swung to the other side, but before it becomes fully effective, the other wing will have dropped, probably half as far again as the first wing dropped. During all this time the stick is being held hard back. The pressure on the rudder is maintained until the wing comes level again, when it is once more swung to the opposite side.

This sequence of operations is repeated as often as required. Each time, the wing will drop farther and farther, and more and more rudder will have to be used. The timing of the rudder movement will have to be exact, because, as the wing drops, the nose of the plane tends to swing, and only the rudder can check that swing. To recover from this maneuver, it is only necessary to return the controls to neutral and open the throttle.

The chandelle, in its simplest form, is merely a steep climbing turn, and not very spectacular. But there is an advanced form of chandelle that is really an acrobatic maneuver. In it altitude is gained while making a 180-degree turn. The maneuver begins with a gentle dive, with the throttle retarded to keep the engine speed below its maximum. The dive will gradually increase the speed of the plane. When the speed is a little more than the airplane's fastest level-flight speed, the stick is moved gently but firmly to the

right (for example) until the right wing is lowered to about 30 degrees. At the same time, the nose of the plane is kept on a straight course by a slight pressure on the left rudder bar.

With the plane flying in a banked position, the stick is moved to the center, and then straight back. The pressure on the left rudder is relaxed at the same time. The plane, by this time, will have come out of the dive and will have begun rising. As the nose comes above the horizon, the engine speed is increased by gently pushing open the throttle. By the time the throttle is wide open, the plane should be through the first 90 degrees of the turn, in an almost vertical bank, with the nose well up.

The next 90 degrees of turn is made while the plane is brought level again and the climb completed. To regain a level attitude, the stick is moved lightly to the left, but the back pressure on it is maintained. At the same time, the left rudder bar is pressed lightly. These pressures are maintained to such a degree that the wing will become horizontal exactly at the end of the 180-degree turn. In coming out of the turn the plane will still be climbing, and probably on the point of stalling. Straight and level flight is therefore resumed by easing the stick to neutral. The actual speed of the plane at this point will be very slow, and the throttle is left wide open until cruising speed is attained.

The Cuban eight consists of two loops which form a vertical figure eight (an eight lying on its side) in which the plane flies in an inverted position through the top halves of the loops. The first loop is started with the plane right side up and in a gentle dive, as in the first part of the chandelle. The engine is throttled back so that it will not turn too fast as the plane's speed increases, and thus damage itself. When the pilot deems the speed sufficient, he pulls gently back on the stick and the plane swings upward at an ever-increasing angle. At the same time, the throttle is gradually opened so that it is wide open by the time the plane is climbing vertically.

As the plane comes into the top of the loop, it will be upside down. At this point, the pilot begins to pull the stick back as far as it will go. Until the top of the loop is reached, the horizon will have disappeared, but at that point it will become visible again,

this time upside down, and the pilot will be able to check the level of his wing. Now the throttle is set at about one quarter open, and the stick is pushed forward sufficiently to bring the nose of the plane just below the horizon. Since it is now beginning the downward part of the loop, the plane will gain considerable speed, and this is needed in order to roll the plane right side up again.

As the stick moves forward beyond the neutral position, the pilot pushes it all the way toward the side to which he wishes to roll. At the same time, he applies opposite rudder to keep the nose of the plane straight ahead. But the moment the roll begins he reverses the rudder, moving it to the same side as the stick. The plane is now right side up and in a dive which will give the plane impetus for the second loop.

In the dive, the throttle is opened a little farther, from which point the new loop is made in the same manner as the first one, but in the opposite direction. If the roll in the first loop was made to the right, the roll in the second one should be made to the left.

The Immelmann turn is a difficult maneuver that calls for more engine power than the usual training or light plane possesses. The reason for this is that the plane has to make half a roll at the top of a loop where it has little speed, and the controls, therefore, are not fully effective. The maneuver is practically the same as the first half of the Cuban eight, but a greater initial speed is required and the loop is tighter (of smaller radius).

The engine is kept throttled down during the entering dive until sufficient speed is attained. Then the stick is eased back and the throttle opened steadily to full-open position. At the top of the loop, while the nose of the plane is still above the horizon (inverted, of course!), the stick is pushed forward of neutral, and moved to the side it is desired to turn. At the same time, opposite rudder is applied for an instant, and then swung to the same side as the turn.

As in the case of the Cuban eight, this will roll the plane into normal flying position. As it comes horizontal, the stick must be eased back enough to keep the nose slightly up and prevent undue loss of altitude. When the plane recovers its cruising speed, the throttle is returned to that setting.

The Cuban eight and Immelmann both involve a roll which is an interesting maneuver in itself. There are many kinds of rolls—the slow roll, half slow roll, half roll, and reverse, snap roll, and so on—all of which consist of turning the plane around its longitudinal axis. In addition to being satisfactory and useful maneuvers, they

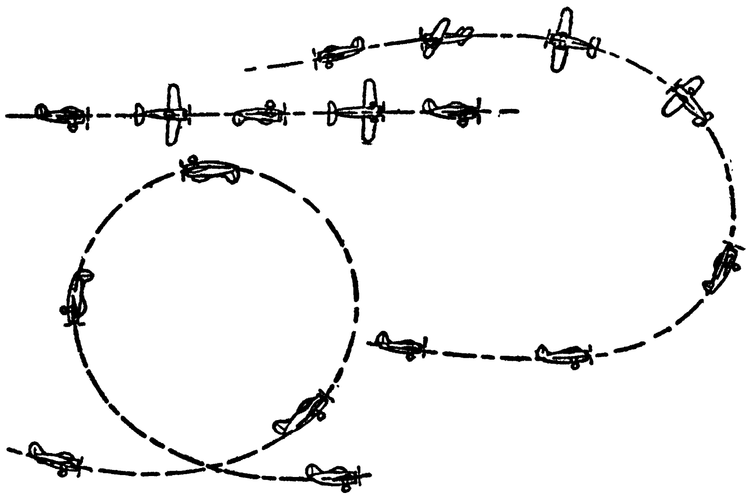


FIG. 91—Lower left: A normal loop; Upper left: Slow, or aileron, roll; Right: Immelmann turn

also familiarize the pilot with inverted flying which is a part of many other maneuvers. Unfortunately, the average light plane engine will not run upside down, and the inverted flight must therefore be made in a glide, with plenty of altitude.

Equally fascinating, both to perform and to watch, are the various loops—most of them simple basic maneuvers—made from either the normal or inverted positions, and starting either with a dive or a climb. In the maneuvers described, which incorporate rolls or loops or combinations of the two, enough has been said to indicate how each roll or loop is performed. The important difference between a good maneuver and a bad one is the degree of precision attained. Almost any pilot can perform fancy maneuvers, when

once he knows how. The true test of his flying skill lies in the smoothness with which he passes from one phase of the maneuver into the next, and the exactness with which he maintains his timing, his orientation and direction. When he begins a maneuver he should know exactly where the plane's nose is going to be pointing when it ends.

CHAPTER X

Effects of Flight on the Body

A HUNDRED years ago, when trains first began to wheeze across the landscape at thirty miles an hour, scientists were fearful of the effects such tremendous velocities would have on the human frame. Today, we hurtle through the skies at hundreds of miles an hour in perfect comfort, and there seems no limit to the speeds that the body can withstand. Our scientists now are satisfied that speed in itself has no detrimental effects. In flying, as we now well know, it is not the speed against which we have to guard, but changes in speed—acceleration and deceleration (or, as engineers prefer to say, positive and negative acceleration), and rapid changes of direction. These can build up dangerous and destructive forces in the body which it is necessary to avoid.

Of equal importance with these centrifugal and inertia forces are the changes encountered in high-altitude flight. Those conditions are the reduced pressure of the air, the lack of oxygen to breathe, and the cold, the effects of which may be noticed at an altitude of 10,000 feet. But this is not all. Almost any motion of the body in flying has some effect on the senses, and, under certain conditions, these effects may be so exaggerated as to be dangerous. High in the air the conditions of orientation and balance are far different from what they are on the ground, and the human organism often has difficulty in adjusting itself to these unfamiliar surroundings.

The whole substance of the matter is that man is not a flying animal, and his sense organs are inadequate for that form of existence without some artificial aids. Fortunately, we now know enough about these things to be able to counteract them and thereby make flying safe under almost all conditions. But knowledge on the part of the flier is essential. In order to fly safely, it is important that the airplane pilot understand the reasons for these inadequacies

of the human body and the precautions he must take to combat them. Lack of such knowledge is always dangerous and has been fatal too many times.

The Senses in Flight

The human body is not constructed for flying, and the senses do not readily adapt themselves to the conditions existing in flight. Normally, on the ground, the eyes, ears, and nerves (the feel of the body) enable us to keep our balance and remain aware of our exact position and attitude at all times. The eyes, particularly, help us to balance ourselves and to move in a straight line as long as our feet are on the ground.

In flight, vision is important in judging position relative to the ground, and in estimating degree of bank or turn, or change of direction. But even when the ground or some landmark is visible, the eye cannot altogether be relied upon in estimating these things. In flight, movements are constantly taking place in three directions —forward, up and down, and sideways, and the only reliable means of keeping track of these changes is by instruments which are not subject to hallucinations, as is the human brain. The senses become too easily confused!

It is because of this constant motion that the eyes often do not get a chance to work alone. Through the nervous system, the eyes, ears, and muscles all affect one another. In the early days of flying, pilots cultivated judgment through experience, and learned to fly "by the seat of their pants." This means that, by their muscular contact with the airplane, they had a good idea what the plane was doing. That was a useful accomplishment, but it was not always reliable, especially in emergencies such as a violent spin, or in zero visibility. Many a pilot has been astonished, on emerging from a storm cloud, to find himself flying upside down.

On the ground, a man blindfolded, or with his eyes shut, relies upon his ears to keep his balance. But even the ears can be confused. The balancing mechanism located in the ear consists of a group of three semicircular ducts or canals. These are bony tubes

with liquid inside them. Two of them are vertical and one is horizontal, and they come together in such a fashion that each is at right angles to the other two. At the point where these canals meet is an enlarged space called the ampulla. Inside the ampulla

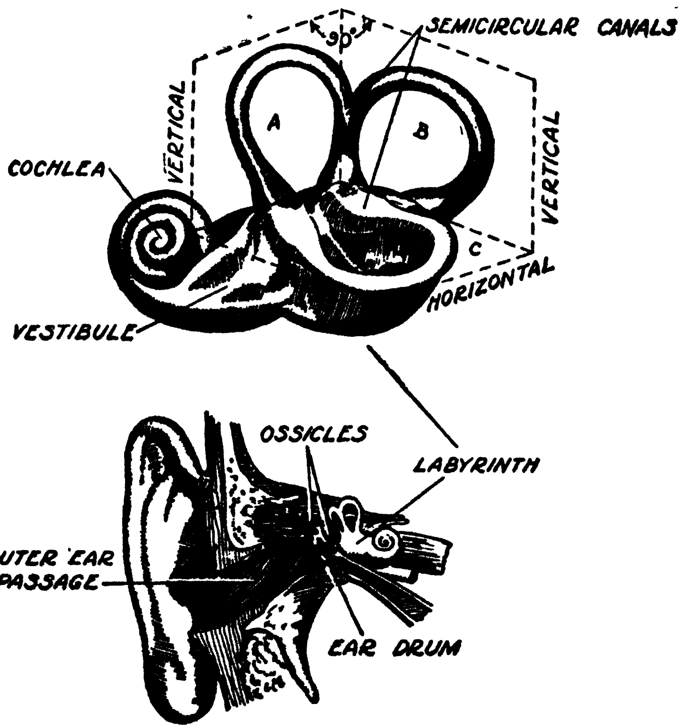


FIG. 92—The human ear and organs of balance

is a group of sensory hairs which can be swayed by any movement of the liquid, just as a field of wheat is swayed by a breeze.

If the head is turned to the right, the horizontal canal turns with it. But, because of inertia, the fluid in that canal does not move as quickly as the canal, and the sensory hairs are bent to the right. This movement of the hairs is transmitted by the nerves to the brain so that the subject is conscious of the direction and extent of

the movement. The same thing applies to the other two canals, and between them the three canals keep their owner informed of his head movements in any direction or plane.

As everyone knows, this works very well under normal conditions. But what happens to a pilot in a spin? As he keeps on turning in the same direction, the movement of the fluid finally catches

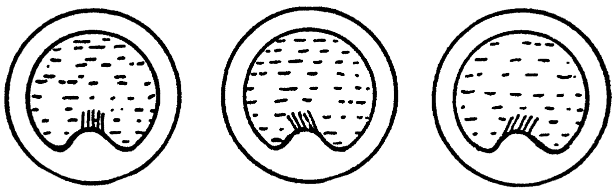


FIG. 93—The ampulla, showing movement of liquid and hairs when head is turned

up with the movement of the canals, the sensory hairs remain upright, and the brain receives a message that the head has stopped turning. If the pilot had neither visibility nor instruments, he might conclude that he had pulled out of the spin.

The opposite reaction is equally misleading. When the pilot pulls his plane out of a spin his head stops turning, but the fluid keeps on moving for an instant. The pilot then has a sensation of turning in the opposite direction, and he needs his eyes to correct this impression.

While the semicircular canals detect motion in any direction, they do not indicate which way is down, or respond to the pull of gravity. To serve this purpose there is another balance mechanism in the inner ear, consisting of two small sacs called the saccule and utricle. These are small hollow bodies also containing sensory hairs in an upright position, but no liquid. On the tips of these hairs are minute crystals of calcium carbonate (lime). These crystals act as weights to bend the hairs when the sacs are tilted, or when there is any linear movement. As long as the hairs are erect there is a feeling of balance, and the slightest movement indicates the direction of the pull of gravity.

This mechanism works perfectly on the ground, but in the air there

are circumstances under which it may be deceptive. In a vertical bank, for instance, the pull on the weighted hairs is more toward the horizon than toward the ground. This might well lead the pilot to think the horizon was below his lower wing tip, or straight down.

Apart from these special organs, the body as a whole helps in balance and orientation. There is a certain muscle sense, due to changes in pressure and tension on the flesh and internal organs. All of these are affected by gravity, change of position, and motion. The body feels the position it is in, and changes in its balance. But in circular motion this, too, is likely to be uncertain, and the eyes are a better guide than the senses.

It is disturbance of the sense of balance that causes air sickness. This disturbance is caused by mental confusion arising from the sensations recorded in the brain by the balancing mechanism of the inner ear, the eyes, and the muscles. Vibration, fear, strong odors, noise, and cold may aggravate the condition.

Effects of Accelerations

All flight is a constant battle against gravity. It is gravity that pulls the plane and pilot down. Normally, when the plane is in level flight, the weight of the pilot is equal to gravity. But under certain circumstances, that force of gravity can be multiplied many times. When that happens, the body is subjected to forces which it is not designed to withstand, and trouble may ensue.

Such extra force will be due to acceleration, and may come as a change in speed or direction. In mechanics, the word acceleration means the change of velocity or change of direction, or the rate of such change. That definition will be used here in discussing its effects on the human body.

As mentioned before, it is not speed that affects the body, but change of speed. In other words, if an airplane is flying at 100 m.p.h. and its speed is suddenly increased to 200 m.p.h., the effect will be the same as if it had suddenly moved at 100 m.p.h. from a standing start. Now, while the body can withstand a steady motion of 200 m.p.h. just as easily as it can a speed of 100 m.p.h., an instantaneous

increase of velocity of 100 m.p.h. would subject it to damaging strains. Something of this nature happens when an airplane is catapulted from the deck of a ship. It is given a sudden, tremendous forward impulse, and if the pilot is not properly cushioned against the shock, he will be seriously injured—he may have his neck broken when his head is suddenly snapped back. Such sudden changes in velocity occur in flight in a number of ways.

Strains due to changes in velocity occur in a crash, when the plane is brought to a sudden stop, and in sudden checking of the fall when a parachute opens after a long drop. Far more common are strains due to change of direction when an airplane goes into a turn, a loop, or a dive. In each of these, centrifugal force plays an important part. These forces which act on the body are measured in terms of gravity. A man weighing 160 pounds is pulled toward the center of the earth with a force equivalent to 160 pounds. That force, due to weight, is equivalent to gravity, represented by the letter G. If that weight is given an acceleration, the force will be increased, with the result that there will be an apparent increase of weight. That increase is measured in G's.

In normal flight, a pilot weighing 160 pounds represents a load of 160 pounds in the plane. If the plane is pulled out of a dive, the pilot's body will have been given an acceleration which will increase his apparent weight several times. If that increase is equal to six times his normal weight, the load is said to be 6 G's. This would mean that the pilot would press down on his seat with a force equal to six times his weight—or 960 pounds! At that instant, he would actually weigh 960 pounds—and he would feel as though he did!

Most pilots can easily withstand accelerations of 4 G's, but at 5 G's or over serious symptoms are likely to develop. In a pullout from a dive at 5 G's, the pilot will probably find his vision clouded. At somewhere between 5 and 6 G's he will probably suffer a temporary complete loss of sight. This phenomenon is called blacking out because the eyes register nothing but darkness. Fortunately, this acceleration is only in effect for two or three seconds as a rule, and the pilot quickly recovers his sight. If the acceleration, and therefore the blackout, continues for more than five seconds, unconsciousness

may result. Even then, when the acceleration ceases, consciousness and sight are restored in five to ten seconds.

The cause of all this is the centrifugal force developed in the pull-out or inside loop, which drains the blood from the head. Between the heart and the head is a column of blood about 12 inches high. When the gravity effect drags the whole body in a downward direction, the blood in the arteries and veins presses downward also. With a pressure of 5 G's, the heart has to work five times as hard to pump the blood into the head, and the effect is the same as making it

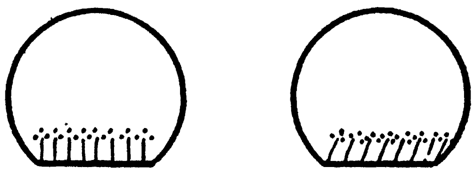


Fig. 94—Principle of the saccule and utricle which respond to the pull of gravity

pump a column of blood 60 inches high! Furthermore, the entire blood pressure in the upper part of the body falls because so much of it has been forced into the abdomen and legs. No wonder that the brain is starved.

In aviation and medical circles, any acceleration which draws the blood from the upper part of the body and forces it into the lower part is called positive acceleration. Acceleration which reverses this process, and forces blood into the head, is called negative acceleration. Negative acceleration is produced when the airplane makes a sudden dive or an outside loop.

In a negative acceleration, force takes effect in an upward direction in the body and the G becomes —G. The centrifugal force, in this case, tends to drain the lower part of the body and to force blood into the head. From a medical standpoint this is even more dangerous, and where a pilot might withstand, with proper precautions, as much as 9 G's with positive acceleration, more than 3 G's of negative acceleration (—3 G) may do serious permanent damage to brain and eyes.

With the blood rushing to the head in an outside loop, the pilot literally "sees red." The blood throws a red curtain over the eyes, the eyes bulge and the head feels as though it would burst. This is called redding out, and recovery from it is considerably slower than from blacking out.

Maneuvers which bring about either redding out or blacking out are not a necessary part of normal flying, and pilots can fly for years without encountering any such circumstance. Only in speed flying, acrobatics, and military combat are such maneuvers necessary, and even the military pilot can do a number of things to avoid them. Outside loops are not made except from sheer necessity, and in diving it is usual to "peel off" instead of making a push-down (tilting the plane on its nose by pushing the stick forward). In pulling out of a dive or in making a tight circle, the pilot tries to increase his muscular and nervous tension, stiffening the leg and abdominal muscles and yelling as loudly as he can.

Those whose business it is to indulge in these acrobatics now have the advantage of a device that has been developed for military combat flyers—the G-suit! Wearing this novel zoot-suit, as the pilots call it, the flyer is enabled to withstand at least one and a half G's more than he could without it.

The device consists of a small, light-weight flying suit equipped with inflatable rubber bladders. There are five of these bladders, one of which rests against each calf, one over each thigh, and the fifth fits snugly over the lower abdomen. The bladders are connected by a hose to a compressed air or CO_2 cylinder, fitted with an ingenious automatic valve.

In straightaway flying, these bladders are uninflated. But the instant there is too much acceleration, the valve shoots air into all five bladders which press against the legs and stomach, resisting the surge of blood to the lower extremities. The greater the acceleration, the greater the air pressure applied, and the stronger the binding effect of the bladders.

Effects of Altitude

At sea level the entire body is subjected to an air pressure of around 14.7 pounds to the square inch. The great majority of human beings have lived under that pressure since the dawn of

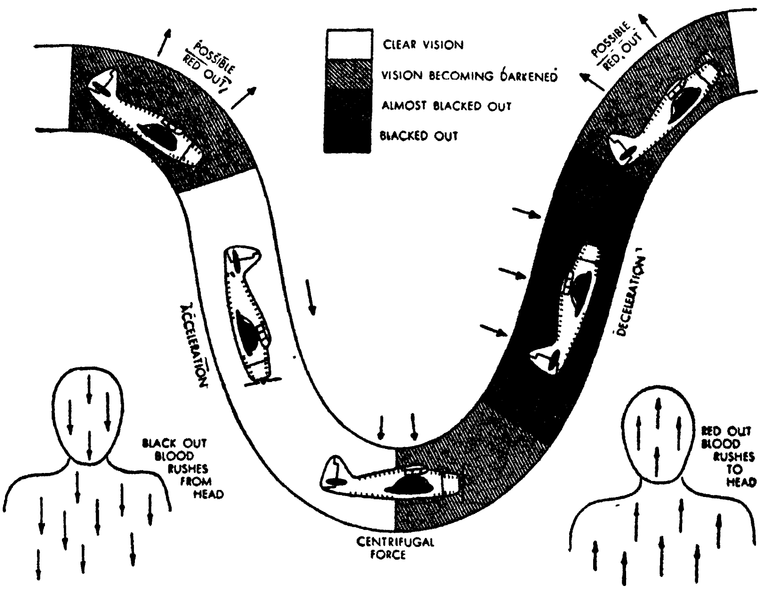


Fig. 95—Black out and red out

history, and it has become a normal condition for their bodies. This means that this pressure exists both inside and outside their bodies, and every part works normally when it is being squeezed to that extent. It is true that people in some countries live at altitudes as high as 16,000 feet, but they have not undergone a sudden transition from one altitude to another; the change has been gradual and may even have occupied centuries.

For most of us, then, a sea-level pressure is normal. If we reduce that pressure rapidly by flying to a great height, the body will only adjust itself with difficulty and at the expense of considerable dis-

comfort and pain. One dangerous condition that is produced by a rapid reduction in air pressure is known as aeroembolism, or the bends.

Aeroembolism is caused by the formation of gas bubbles in the tissues, body fluids, and the blood. At sea-level pressure there is a great deal of gas—principally nitrogen—in the body fluids, fats, and tissues, brought to them from the air by the blood stream. It is kept there by the external pressure of the air on the body and the pressure of nitrogen in the lungs. As that pressure is reduced, the nitrogen begins to escape. Some of it is carried off by the blood, but that process is slow, and bubbles begin to form in the tissues, and even in the blood. There is considerable pain, and bubbles may pass into the smaller blood vessels, shutting off the circulation there. If very large bubbles form in the blood, they may choke an artery and so cause death.

Usually, these bubbles begin to collect faster than the blood can carry them off only at altitudes of 30,000 feet or over. Sometimes, pain may be felt below 30,000 feet, but it is generally mild, and will disappear if the altitude is not increased. If the altitude is increased, the aeroembolism may become so severe that the limbs are paralyzed. A burning sensation may be felt in the lungs, accompanied by stabbing pains and coughing. This stage is called the chokes; it may be followed by a feeling of suffocation, and finally unconsciousness.

Descent to 25,000 feet will usually relieve all symptoms of the bends, but the chokes may not disappear at once. Fatigue will probably be felt for some hours, but no permanent injury will result from either the chokes or bends.

If it is necessary to make an extended flight at altitudes of 30,000 feet or over, trouble can often be avoided by breathing pure oxygen for forty-five minutes beforehand, and by inhaling 100 per cent oxygen all the way up. This eliminates the pressure of the nitrogen in the lungs, permitting a great deal of that which is in the blood and tissues to escape. This process is called denitrogenation.

The release of gas in the tissues is not the only detrimental effect of reduced air pressure due to altitude. Gas in the digestive tract

also may have unpleasant consequences. There is always some air in the stomach and intestines, together with gas generated by digesting foods. At 18,000 feet the atmospheric pressure is half what it is at sea level. The pressure on the body, therefore, is half of what it normally is and the gases inside can therefore expand to twice their normal volume. At 27,000 feet they will have expanded to three times their volume, and at 35,000 feet they will occupy five times as much space as they did on the ground.

The tendency, therefore, is for the body to swell, but this is kept within limits by belching and the passing of gas. At 30,000 feet, abdominal cramps may be experienced as a result of gas becoming pocketed in the intestinal loops. More serious than this, however, is the effect of the expanded intestines pressing on the organs in the chest cavity. This pressure forces the liver up against the diaphragm, preventing its proper movement and so restricting breathing. This will cause discomfort, pain, or even fainting.

Altitude and Breathing

Oxygen is necessary for life and we obtain it from the air by breathing. Muscular action of the chest and diaphragm causes the lungs to expand and draw in air. By relaxing the chest muscles and diaphragm, the air is pushed out of the lungs. During this process of inhaling and exhaling the air, the lungs let the oxygen pass into the blood, and permit carbon dioxide to escape from it. This process is made possible only by the varying pressures of the gases.

The lungs consist of millions of tiny air sacs or pockets, separated from a network of fine blood vessels by a delicate membrane. So thin are the walls between the blood and the air that any difference of pressure between the gases on the two sides will cause the gas to pass from the side of higher pressure to the lower. Now, in any mixture of gases, such as air, the pressure of the individual gases is not the same as the pressure of the air itself. This is explained by Dalton's law of partial pressures, which states: In a mixture of gases each gas exerts a partial pressure equal to that which it would produce if it alone occupied the whole space occupied by the mixture.

The pressure of the atmosphere is most accurately measured with a mercury barometer, which is a tube of mercury sealed at the top and set vertically in a cup. The pressure of the atmosphere on the mercury in the cup will support a column of mercury in the tube (there is a vacuum above the mercury), the height of the column

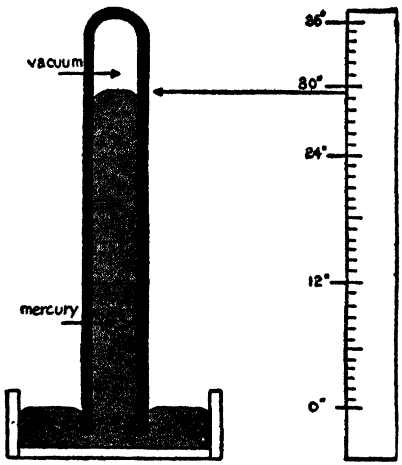


FIG. 96—Principle of the mercurial barometer

depending on the air pressure. At sea level the column will be 760 millimeters (mm.), or nearly 30 inches. At 18,000 feet the column will only be 380 millimeters, and at 30,000 feet it will have dropped to 225 mm.

These are the pressures of the whole air. But since oxygen only forms 21 per cent of the air, it is responsible for only 21 per cent of the total air pressure—160 mm. at sea level. This is the partial pressure of oxygen, and it governs the amount that can be taken into the blood stream at various altitudes. Since the pressure and density of the air decrease with altitude, so does the pressure of the oxygen. This means that less oxygen can be drawn into the blood by merely breathing the air.

When the air pressure is too low to force oxygen into the blood a serious condition results, which is called anoxia or oxygen want.

It starts when the amount of oxygen in the blood falls below 95 per cent of saturation. At a little over 10,000 feet altitude, the saturation will be only 85 per cent. The immediate symptoms are a feeling of exhilaration and well-being, but shortly the oxygen lack will affect the brain and spoil the judgment.

At 13,000 feet the saturation drops to 80 per cent, the hands begin to tremble and the memory is clouded. At 18,000 feet the blood's oxygen content is only 70 per cent—about as little as the body can stand. The muscles are stiff and painful to move, double vision and fainting, and the bluish tinge of the hands and face, warn of approaching loss of consciousness.

Logic would suggest that the way to get more oxygen into the blood at these high altitudes is to fill the lungs more frequently by breathing faster. Unfortunately this will not work, because quick breathing washes carbon dioxide out of the blood too quickly, and it is carbon dioxide that regulates the rate of breathing. Normally, the more carbon dioxide there is in the blood, the deeper and faster will the breathing be. This works perfectly on the ground because there the need for oxygen depends on the amount of work the muscles are doing. The more work, the more carbon dioxide is given off, and the greater the need for breathing faster.

At high altitudes, on the other hand, there is no increase in the amount of carbon dioxide in the blood, and forced breathing would decrease it below normal. This would cause the respiration to be slowed down and would reduce the amount of oxygen getting into the blood. The only ways of increasing the oxygen supply without upsetting the carbon dioxide balance are, to increase the pressure of the air or the percentage of oxygen in the air that is breathed. The air pressure can be increased with pressurized cabins, and the use of special suits and helmets. The percentage of oxygen in the air can be increased by the use of an oxygen mask, and this is often the best and simplest way. By the use of the mask, the pressure of the oxygen entering the lungs can be raised from the normal 21 per cent to 100 per cent, if need be. With such a mask flights can be made at altitudes up to 40,000 feet.

With the mask any reduction in partial pressure of the oxygen

in the air is offset by increasing the percentage of oxygen. At sea level, for example, the percentage of oxygen is 21 and the partial pressure is 160 mm. At 18,000 feet the percentage of oxygen is still 21 per cent, but the partial pressure is only 80 mm. Now, if the

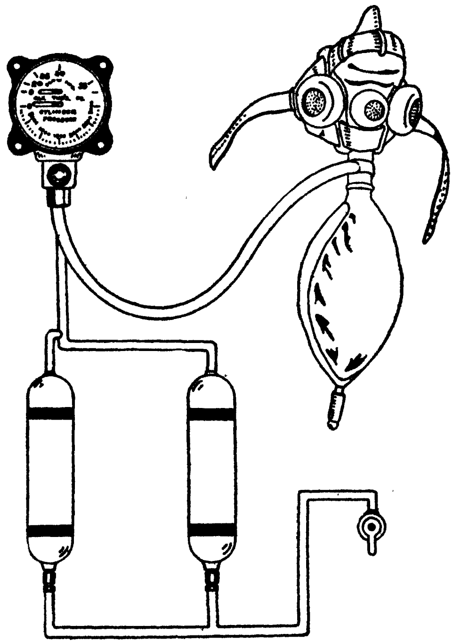


FIG. 97—Low-pressure, continuous flow oxygen system

proportion of oxygen is raised from 21 per cent to 42 per cent (at 18,000 feet), its partial pressure will again become 160 mm. This system can be followed up to an altitude of 34,000 feet, at which 100 per cent pure oxygen is needed.

Since it is impossible to supply more than 100 per cent oxygen to the lungs at altitudes of over 34,000 feet, the partial pressure falls off. Any increase of altitude, therefore, is made at the expense of decreasing the amount of oxygen in the blood. At 40,000 feet, with 100 per cent oxygen, the blood's oxygen content is reduced to the danger point, and continued operation at that level is not safe.

Two types of oxygen supply equipment are used on modern airplanes. One is the demand oxygen system; the other is the continuous flow oxygen system. Since the continuous flow system is gradu-

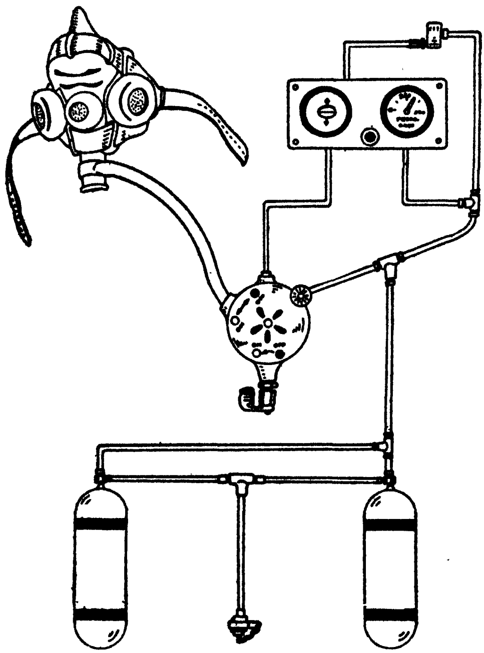


FIG. 98—The demand-type oxygen system

ally being replaced by the demand type, only the latter system will be described.

As its name implies, the demand system supplies oxygen as it is required. This effect is secured by means of a valve which lets oxygen pass to the mask whenever the wearer inhales. The complete system consists of a low-pressure oxygen cylinder containing oxygen compressed to 400 pounds to the square inch. This is coupled to a supply line, one branch of which goes to a pressure indicator on the airplane's instrument panel, and the other branch to a regulator valve. The regulator reduces the pressure of the oxygen from the

cylinder to that required for the mask, and a warning light goes on when the oxygen supply pressure falls to 100 pounds.

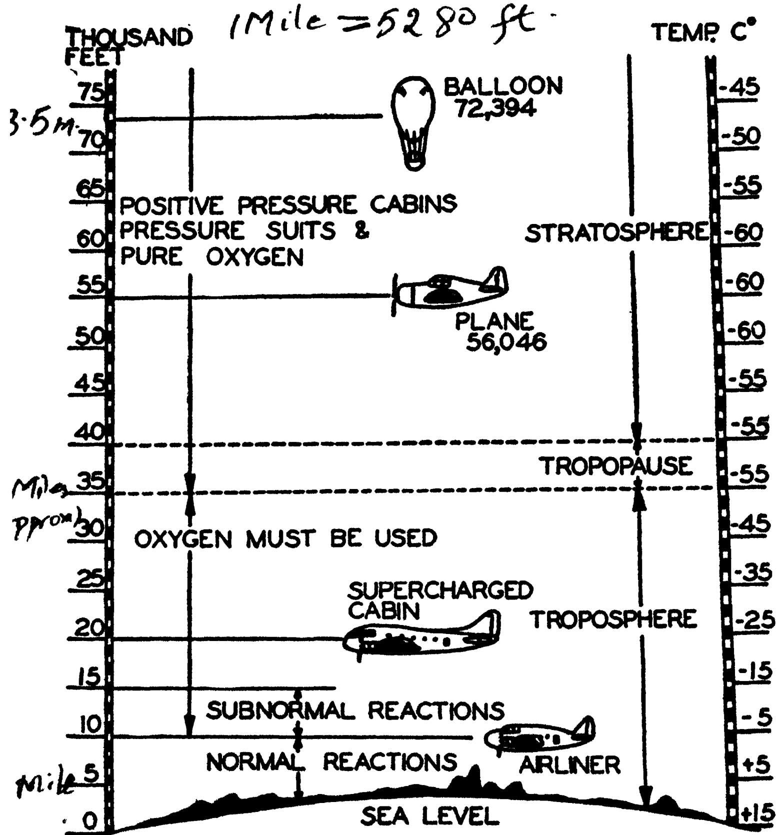


FIG. 99—Altitude and the use of oxygen

Inside the regulator is a tiny bellows which is actuated by the pressure of the outside air. This bellows controls a valve which regulates the amount of air and of oxygen passed to the mask. At sea level it passes all air and no oxygen, and gradually shuts down the amount of air as altitude is increased. At 30,000 feet it passes all oxygen and no air.

The mask fits tightly over the nose, mouth, and chin so that no air leak is possible between it and the skin. Built into it is a flap valve which opens to discharge the used air on exhaling. A flexible tube connects it with the regulator outlet to which it can be attached or detached at will. In case it is necessary for the wearer to walk around in the plane, or to make a parachute jump, a special portable oxygen cylinder can be used. This is known as a walk-around bottle, which contains a four- to eight-minute supply of the gas. The mask is plugged into it, and the bottle is attached to the clothing by a clip.

Night Sight

No one can see as well in the dark as he can in the light, but in night flying the vision can be enormously improved by the proper use of the eyes. Sight is made possible by the light-sensitive retina which forms the back wall of the eyeball. The surface of the retina is composed of a great many tiny projections. These projections are of two kinds. In the center of the retina they are conical in shape, and are therefore called cones. The rest of the retina is lined with straight-sided projections called rods, with a few cones scattered through them.

The central area, then, is composed of cones, which work best in the light, and can distinguish detail and color. The rods, on the other hand, are useful at night because, although they are not sensitive to color or detail, they do detect motion, and transmit images to the brain in various shades of gray. Therefore, good daylight vision is little guide to the individual's ability to see well at night.

At night the cone area is practically useless, and acts almost as a blind spot. The rest of the retina is about a thousand times more sensitive in a poor light. In night flying it is therefore necessary to use the outer portion of the retina, which means that, instead of looking directly at an object, it is better to look to one side of it. The blind spot does not then interfere with the vision, and the object will be seen much more clearly. By practicing this trick in dim light, the power of the night vision can be greatly improved—and in some instances even doubled.

CHAPTER XI

The Air and the Weather

THE EARTH is a ball of rock whirling in space. The atmosphere is a thin skin of air that clings to it—held there by the same force of gravity that keeps the oceans from flying off into the void and tugs with greedy fingers at airplanes in the sky. This atmosphere surrounds the earth like a deep ocean, and we, and the rest of the world's inhabitants, live at the bottom of that invisible sea. But, although this air ocean is deep, as oceans go, a great deal of it is of little or no direct use to aviation.

The atmosphere extends upward from the surface of the earth to a distance of about 620 miles. At that point the air is so thin that it can hardly be called air at all. Beyond that there is supposed to be nothing but the outer space, in which the planets, stars, and meteors move, and vast clouds of cosmic dust hang seemingly motionless.

Since the earth is around 8,000 miles in diameter, the layer of air over its surface is very shallow in comparison. Yet, in that thin layer of air, all of today's flying is done within eight miles of sea level—one seventy-seventh of the atmosphere's total depth! Nevertheless, in these lower levels of the air ocean, airplanes can travel from any point on this earth's surface to any other point. For the airplane, geographical boundaries and physical barriers do not exist. In this air age, planes can be made to fly over the highest mountains, if need be, and to cope with all the conditions they will meet in their journeys over the poles or across the equator—in temperatures of 60 below zero or 120 degrees above, in air that is dense or in air that is thin! This does not mean that there are not tremendous problems to be solved—problems posed by the very nature of the air itself.

It is air which limits the speed at which airplanes can fly. And

it is air, or the lack of it, which limits the height to which they can go. This air which composes the atmosphere is a mixture of gases and water vapor. The proportions of the various gases change slightly with altitude, but near sea level there is about 78 per cent nitrogen, 21 per cent oxygen, the remaining 1 per cent being made up of carbon dioxide, argon, hydrogen, helium, xenon, and krypton. The amount of water vapor varies. In the lower atmosphere it will average about 1.2 per cent, decreasing at higher altitudes so that the upper air is practically dry.

The atmosphere is divided into several horizontal layers. The layer nearest the earth is called the troposphere. Over the poles the troposphere extends to an average altitude of about five miles, and over the equator, eleven miles. In this layer of air the weather is made. Here are the vertical currents and winds, the clouds, and precipitation. In the troposphere the temperature of the air generally decreases with altitude at the rate of 3.6 degrees F. for each 1,000 feet, although warm currents may occasionally rise to high altitudes.

Over the troposphere is the outer layer of air, the stratosphere. In the stratosphere there are no vertical air currents, no clouds, and no weather. The boundary between the troposphere and the stratosphere, sometimes called the sub-stratosphere, is the tropopause. In it the temperature is constant at —69.7 degrees F. Above it, in the stratosphere, such winds as there are are parallel with the surface of the earth. The temperature here, as in the troposphere, gets gradually less until an altitude of about fifteen miles is reached, when the thermometer drops to —113 degrees F. After that, however, the temperature begins to rise again. At eighteen miles it is —58 degrees F., and at 31 miles it has risen to 158 degrees F.

The stratosphere extends as far as the outer space, but it is divided into a number of layers where the air has become ionized (i.e., broken up into electrified particles) by electromagnetic waves radiated from the sun. These bands or strata are classified as the ionosphere.

Air has weight. Anything on the surface of the earth at sea level is pressed down upon by a column of air 620 miles high. The weight

of that column is 14.7 pounds to the square inch (over a ton to the square foot!). The air forming the upper part of the atmosphere presses down on the air beneath it, and, because that air, like all gases, can be squeezed into a smaller space (compressed), it becomes denser and more dense as it approaches the surface of the earth. Conversely, it becomes less dense at higher altitudes. Because the lower part is squeezed into a smaller space, half of the air in the atmosphere is below the 35,000-foot level. The pressure at 18,000 feet is only half of what it is at sea level, and at 36,000 feet is but a quarter of 14.7 pounds.

This reduction in pressure at increasing altitudes means that the air is becoming progressively less dense. Like all other matter, air is made up of infinitely small particles called molecules. The density of a substance depends on the number of molecules in a given space. The more molecules, the denser will the substance be.

In the case of gases like air, the size of any quantity of it varies according to its pressure and temperature. If, for instance, 10 cubic feet of air are squeezed into a space of 1 cubic foot, that air will have become ten times as dense as before, for there will be ten times the number of molecules in the same space. It is, therefore, easy to see that air at sea level, which is squeezed by the weight of 620 miles of air above it will be much denser than air at an altitude of several thousand feet, where the column of air above it is that much shorter and made up of less dense (and therefore less heavy) air.

With more than half the air below the 35,000-foot level (seven miles), it is not surprising that the air above that point rapidly becomes so thin with increasing altitude that there is hardly any air at all in comparison with the troposphere. At fifty to sixty miles the air may be so thin that it no longer acts as air. The molecules are so widely separated—instead of 27 sextillions to the cubic foot there may be only one to the cubic yard—that their presence can only be detected by their reaction to the electromagnetic waves radiated from the sun.

This extremely thin air of the stratosphere, bombarded by the sun's rays, becomes ionized. These ionized particles form layers at

various altitudes from eighteen to 130 miles. These are the D layer, the E, or Kennelly-Heaviside Layer, and the F, or Appleton, Layer. There is one important difference between these layers, and that is that they reflect different radio wave lengths and cause such phenomena as fading and skip distance. The D Layer reflects long radio waves; the Heaviside Layer reflects ordinary broadcast waves (200 to 550 meters), and the Appleton Layer reflects short waves. In the uppermost of these layers the auroras are seen—in the north the aurora borealis, in the southern hemisphere the aurora australis.

The factor of density is of vast importance to aviation in several ways. The denser the air, the greater will be its resistance to an airplane flying through it. If the airplane flies twice as fast, the air resistance will be four times as much. Very high speeds at low altitudes are therefore costly in power. On the other hand, if the airplane can be made to fly at a high altitude, say 25,000 to 35,000 feet, it will be able to travel at proportionately higher speeds because of the reduced resistance of the air. That is why long distance flights can be made economically at high speed in the sub-stratosphere. The engines will consume the same amounts of fuel and put out almost the same amount of power as at lower altitudes, but the propeller blades will be set so that they take bigger bites out of the air and therefore pull the plane along faster.

But there is far more to high-altitude flying than this. As was mentioned, the air temperature at high altitudes is well below zero. This means that crew and passengers must be thoroughly protected from cold, either by heated flying suits or a heated cabin. The engine, too, must be kept warm so that the carburetor does not freeze or the oil get too thick, or the rubber insulation of the ignition wires disintegrate.

Then there is the problem of air pressure. At 25,000 feet the pressure is only one third of what it is at sea level. Its effects on the human body were discussed in the last chapter. The engine, too, is affected. At 40,000 feet gasoline begins to boil and the gas lines become locked. The insulation in the electrical equipment is no longer effective, and the electricity is dissipated in sparks to ground. With the air so thin, the engine can no longer get its full supply of

fuel mixture and its power falls off. Even at 25,000 feet some of these troubles may be experienced. But they can be, and are, taken care of. Air-tight cabins are used in which the temperature and pressure of air are maintained at comfortable levels. Carburetors and oil systems are heated; electrical systems are enclosed in tubes which are full of air at near normal pressure, and so on.

Investigating the Upper Air

Considerable exploration has been carried out in the higher reaches of the atmosphere, but there are still many things that are

Fig. 100—A radiosonde consisting of balloon, parachute and instrument assembly

not known. So far, it has been quite impossible for any human being to ascend very far into the stratosphere. The highest altitude that any man has reached is 72,394 feet. This was accomplished by the use of a balloon, from which was suspended a metal sphere inside which the explorers traveled. The sphere was supplied with warmed air at a safe pressure and with an adequate supply of oxygen. Instruments carried inside and outside the sphere recorded tempera-

tures and pressures and the presence of mysterious emanations from outer space, called cosmic rays. Carried out at great risk and tremendous expense, this voyage into the air ocean extended less than fourteen miles—one forty-fourth of the way to the top of the air!

Better success has been had with radio sounding balloons—the radiosonde. These balloons, about 6 feet in diameter, have carried instruments up as high as 130,000 feet. The instruments consist of altitude, pressure, temperature, humidity, and rate-of-change of temperature recorders. The readings of these instruments are automatically broadcast by a tiny radio transmitter, and are recorded at meteorological stations on the ground. When the balloon reaches its maximum altitude it generally bursts, due to expansion of the gas inside it and the low atmospheric pressure outside. A parachute suspended below it then opens, and the instrument box falls gently to earth.

On clear days the ascent of the balloon and its drift in any direction can be watched through the telescope of a theodolite, by which its horizontal travel and direction can be measured. This gives evidence of any horizontal winds in the upper air.

By similar means, such as the use of two of these angle-measuring instruments a considerable distance apart, the heights of various phenomena can be calculated. Other devices involve the use of photographic cameras and radio transmitters. By such means the heights of various ionized layers, the auroras, and even meteorites, can be gauged.

Meteorites, which only become visible when they are heated to incandescence due to air friction, have been recorded at a height of 200 miles. This indicates that the air must be appreciably dense at that altitude. The auroras, which are probably the result of electrical discharges in the thin air, have been observed at more than 600 miles altitude. This is one indication that the atmosphere extends at least that far, although it may be so thin as to be practically non-existent. As in the case of the lower atmosphere, most of the phenomena encountered in the upper atmosphere are due to the light and heat and electrical rays emanating from the sun.

The earth is 91,000,000 miles from the sun in winter, and 94,000,000

miles in the summer—those seasons, of course, referring to the Northern Hemisphere. The reason that the sun warms the Northern Hemisphere most when it is farthest away is that the axis of the earth is tilted, and the sun's rays strike the earth almost vertically in summer. The result is that during the summer the sun's rays have to pass through considerably less atmosphere before reaching the surface of the earth.

The fact that the rotation of the earth causes the air envelope to bulge over the equator has a peculiar effect on the temperature of the atmosphere at the level of the tropopause. At the latitude on which New York is situated, the temperature of the air next to the tropopause is usually about —67 degrees F. Over latitudes bordering the arctic circle, that temperature may be —49 degrees F., while over the equator it is no less than —112 degrees F.

On the face of it, it would seem that the temperature over the equator would be highest instead of lowest, but it must be remembered that the tropopause at that latitude is several miles higher than it is over the polar regions.

The rays with which the sun bombards the earth are of many different kinds, and all may be grouped under the term "electromagnetic." While they do not influence the flight of an airplane directly, they affect the temperature of the air at various altitudes. Therefore, they affect the weather, and may sometimes interfere with radio communication. Their differences are due to their wave lengths, and they include not only light and heat waves, but gamma rays and radio waves. The speed of light, and all other electromagnetic waves, is 186,000 miles per second. That is to say, the wave travels 186,000 miles (or 300,000,000 meters) each second. If the length of each wave is small, it is clear that there must be a great number of them generated in one second to extend that tremendous distance. That number is called the frequency, and the shorter the wave length, the greater the frequency.

A great many of these radiated waves are very small indeed, and a small unit is used to measure them. This unit is the micron which is equal to 1,000th of a millimeter. Visible light may have wave lengths of 0.38 micron to 0.78 micron. White light is composed of

seven colors—red, orange, yellow, green, blue, indigo, and violet—with the reds having the longest wave lengths and the violets the shortest. Below the violet is the ultra-violet band of frequencies,

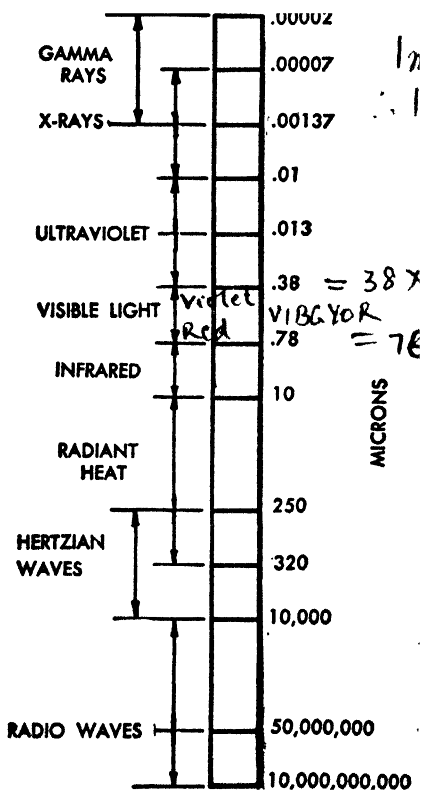


FIG. 101—Electromagnetic spectrum, showing lengths of waves emitted by the sun

ranging from 0.013 to 0.38 micron. These rays are invisible, but it is they which cause sunburn, and the formation of vitamin D in the skin. These rays are easily stopped and absorbed. At the other end of the scale are the infra-reds which are the heating rays. Their wave lengths vary from 0.78 to 10 micron.

The average amount of solar energy striking 1 square foot of the top of the atmosphere would be sufficient to raise the temperature of a pound of water 7.15 degrees F. per minute. Exposure to this energy is referred to as insolation and, luckily for mankind, little of that energy reaches the surface of the earth to stay there.

This, then, is a picture of the atmosphere as a whole. It acts as a shield around the earth, protecting it against the impact of meteorites and the bombardment of the sun's rays, filtering out much of the harmful things and letting pass much that is beneficial. As far as high altitude flight is concerned, the upper part of this atmosphere is valueless, as yet. But it is of great importance to aviation in one respect, for what takes place in the higher reaches of the air is not without its effect on the layers nearer the earth where flying is done. If this protective envelope did not have the characteristics it has, conditions in the lower atmosphere would be far different, both for flying and for living.

The point to remember is that if the heat received by the earth from the sun was not dissipated into space, or converted into some other form of energy, the earth's surface and the air would grow constantly hotter. Water vapor plays an important part in this because it is the water vapor which does most to absorb some of the shorter waves and re-radiate them as longer heat waves. Surface radiation is cut down by clouds and water vapor near the earth, and on the equator more of the sun's radiation is absorbed than is re-radiated into space. Nearer the poles the reverse is the case, and this fact has a great deal to do with the primary circulation of the atmosphere, which is discussed later. In such ways, then, the whole atmosphere plays a part in the distribution of temperatures in the troposphere where the weather is made.

How Weather Is Made

The science of the weather is called meteorology, and, since certain weather conditions make it hazardous or impossible to fly, a knowledge of meteorology is of first importance to everyone concerned with the operation of airplanes. Such things as fog, high

winds, lightning storms, coldness, and humidity affect the airplane in flight. The pilot, therefore, should be able to identify the various atmospheric conditions that lead to these things, and understand the effect they will have on his projected flight. The first step in this direction is to study the causes of the various kinds of weather, the greatest single influence being the sun.

The heat of the sun is the prime cause of all air currents and other changes that take place in the atmosphere. Many of these changes and motions are caused by the fact that the heat which the sun supplies to the ground and the air is distributed unevenly. Very little of the heat is picked up by the air from the sun's rays directly. The rays pass through it so rapidly that they raise its temperature very little. When they strike the surface of the earth, however, they are absorbed much more readily, and warm the area exposed to them in varying degrees. Water, for example, absorbs the heat more slowly than the land and holds it longer, and certain kinds of land surfaces absorb heat faster than others. This heat, being re-radiated from the various surfaces, warms the air above them, slowly or rapidly as the case may be.

The amount of heat absorbed by the earth's surface also varies according to the geographical location. At the Equator more heat is absorbed by the earth's surface than is reflected, because of the comparatively dark surfaces and the large amount of water vapor in the atmosphere. At the poles most of the heat is reflected by the snow and ice. At night time a great deal of the absorbed heat is re-radiated.

These wide variations in temperature all over the earth act upon the atmosphere in such a manner as to produce the various conditions called weather. These conditions are due to the special properties of the atmosphere and the matter suspended in it. The lower atmosphere is a mixture of gases of varying densities, including an average of about 1.2 per cent of water vapor. These gases expand when they are heated and contract when they are cooled. When heated air expands it becomes lighter in weight; when it is cooled it becomes heavier. Because of this, the air warmed by radiation from the earth's surface rises, and its place is taken by colder air

from above or around it. This air movement may be gentle, or it may be rapid and violent. In any case, it sets up currents which may be in a vertical or horizontal direction, or a combination of both. This is the manner in which winds are born.

Apart from these comparatively local air movements in which cold and warm currents flow through the atmosphere, the temperature of the general body of the air is always warmer nearer the surface of the earth. It is changes in temperature or pressure or density that are responsible for other weather phenomena such as clouds, rain, hail, snow, lightning, etc. Among the most important of these phenomena, or meteorological elements, from the aviator's viewpoint, are the clouds.

Clouds are condensed moisture in the air, caused by the cooling of warm air as it rises or comes into contact with a mass of cooler air, or with a solid surface such as a mountain peak. The warm air, being able to absorb more moisture in the form of water vapor, can no longer contain it all when it cools. The excess vapor then condenses into minute drops of water which are visible as clouds. When clouds form at very high altitudes, the moisture freezes and remains suspended in the air as very fine particles of ice.

Because clouds are an indication of physical changes taking place in the atmosphere, they are most helpful in determining weather conditions. They are classified according to their altitude, shape, size, and general appearance. The average lower level of the highest clouds is about 20,000 feet, and these may be classified in three general groups:

1: Cirrus clouds of ice particles, of thin, feathery texture, having the appearance of streaks of cotton fibers.

2: Cirrocumulus, thin, flake-like clouds formed of small cloud clusters, with a rippled under surface of vapor or ice particles.

3: Cirrostratus, thin, wispy sheets of cloud forming a layer over a large portion of the sky. Sometimes a halo appears around the sun when seen through these clouds, due to the refraction of the sunlight by fine ice crystals.

Usually, these three types of clouds are at such a high altitude that they are composed chiefly of ice dust, which gives them their

feathery appearance. The middle group of clouds is found at altitudes of 6,500 to 20,000 feet. These are:

4: Altocumulus, which are similar in appearance to cirrocumulus, except that the cloud bunches are larger and more clearly defined. They may appear as a large, flat sheet of small white puffs.

FIG. 102—Cirrus (Mares' tails)

FIG. 103—Cirrocumulus clouds

5: Altostratus, a medium-high, uniform sheet cloud, like a fibrous veil, gray or bluish in color. The sun or moon shines through it with a faint glow, as through ground glass.

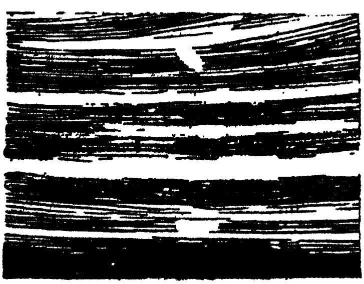


FIG. 104—Cirrostratus clouds

FIG. 105—Stratocumulus clouds

The third cloud family consists of low clouds at altitudes of 6,000 feet to the ground level. They are:

6: Stratocumulus, dark globular masses, like elongated rolls of clouds. They have a soft appearance, with gray or dark spots. Sometimes they are all gray.

7: Stratus, a low, uniform sheet cloud that resembles fog, not resting on the ground.

The last type of cloud has a vertical as well as horizontal development. Such clouds extend from as low as 1,000 feet to sometimes more than 20,000 feet. They are:

8: Cumulus, a dense, dome-shaped, puffy, cottony cloud, often observed on hot days during the summer. It is formed by the condensation of moisture from rising thermal air currents in the cold higher atmosphere.

FIG. 106—Cumulus clouds

FIG. 107—Cumulonimbus cloud

9: Cumulonimbus, a heavy mass of cloud with a great vertical development. It has the appearance of a huge mountain in the sky, with its lower parts commonly dark in color and its upper reaches white and feathery, often spreading out in the shape of an anvil. These clouds generally produce showers of rain or snow, sometimes hail, and often thunderstorms as well.

Fog is a cloud that is close to or on the ground. Fogs are not usually formed by the cooling of rising warm air (convection), but in several other ways. There are air mass fogs, formed by the lowering of the temperature of horizontal air currents; frontal fogs, formed by the addition of water vapor to the cold air from the warm air, or from a combination of these two effects. Three types of air mass fogs are: (a) advection, (b) radiation, and (c) upslope fogs.

An advection fog is caused by warm, moist air moving over a

cool surface, the word "advection" meaning transfer by horizontal motion. Other advection fogs may be caused by the movement of cold air over a warm, moist surface, as in the case of the so-called arctic sea smoke. Radiation fog may form over rivers, in mountain valleys, or over moist land, when the land or water and moist air are cooled by radiation at night. This "ground fog" will be dissipated by the rising sun. Upslope fogs are often formed by the cooling of moist air due to expansion as it moves to a higher altitude up a gradual slope.

(In addition to forming clouds and fogs, the condensation of water vapor may also turn into dew, rain, snow, or hail) Dew, like frost, is the condensation of water vapor on any object, such as grass, which is cold. Dew, therefore, is deposited; it does not fall, poets to the contrary. Rain, snow, and hail fall to the earth, and this falling is referred to as precipitation. Meteorologists measure this precipitation by means of a rain and snow gauge.

Rain consists of water droplets condensed from a cloud, usually forming around a minute speck of salt or other dust floating in the air, or even on ice crystals. When these droplets grow large enough, they fall to earth. If they form in a temperature near freezing, they may, while still small enough to remain suspended in the air, crystallize into snow drops. These flakes may continue to grow until they are heavy enough to fall. Often, such flakes melt into rain before reaching the earth. Half-melted snow is called sleet, as is half-frozen rain.

Hail is usually formed inside a cumulonimbus cloud. At first it is a snowflake which melts, or a raindrop formed near freezing level. Vertical air currents force it up again each time it starts to fall. Passing through the freezing level, it solidifies into a hailstone, and each time it moves up and down it gathers more moisture from the cloud. Usually, it adds so many frozen layers that it becomes heavy enough to fall to the ground in a short time.

Another phenomenon associated with clouds, which is important to the airman, is lightning. Lightning is an electrical discharge between two parts of a cloud, between two clouds, or between a cloud and the earth. Due to the strong vertical currents in tall cumulus

clouds, and the presence of snow and ice crystals, or because of high temperatures combined with high humidity, static electricity is generated in one or more parts of the cloud. When a negative and a positive cloud mass come together, a discharge takes place in the form of a lightning flash.

Before considering what clouds tell about the approaching weather, it is necessary to know something about air masses and fronts.

When air which has practically the same composition and characteristics covers a large area, it is called an air mass. Such masses often have their temperature and humidity determined by the part of the earth's surface over which they rest. They are therefore classified according to the region in which they acquire their characteristics. These regions are called source regions. While the characteristics of the regions themselves change with the season, air from tropical regions is generally warm, and air from polar regions is usually cold. Likewise, air from a continental area will be dry, and that from over an ocean moist. The general properties of various air masses have been classified. Polar air, for instance, will have a lower temperature than the sea over which it blows. It will be dry near the surface, and will contain convection currents, gusts, squalls, or bumpiness. After leaving its source region, it will develop fair or showery weather, sometimes with thunder and broken cumulus clouds.

The movements of such air masses give rise to "fronts." Such fronts are merely the areas where one air mass comes into contact with another air mass of different temperature. A warm front is the area of contact where warm air has overrun a retreating cold air mass. In a cold front cold polar air is underrunning warm air from the tropics. Under certain conditions, these fronts, which may extend for hundreds of miles, determine the weather. Their presence can be detected by the types of clouds usually associated with them.

Warm fronts are heralded by the formation of cirrus clouds, followed by cirrostratus, altostratus, nimbostratus, and, lastly, stratus. The temperature change will be gradual, and there will be showers.

The weather in a cold front is squally and is preceded by rain, or

sometimes by the formation of cumulonimbus and thunderstorms. The first sign is the appearance of altocumulus or altostratus clouds, the cloud ceiling falling rapidly as the front approaches. Often the temperature drops quickly in advance.

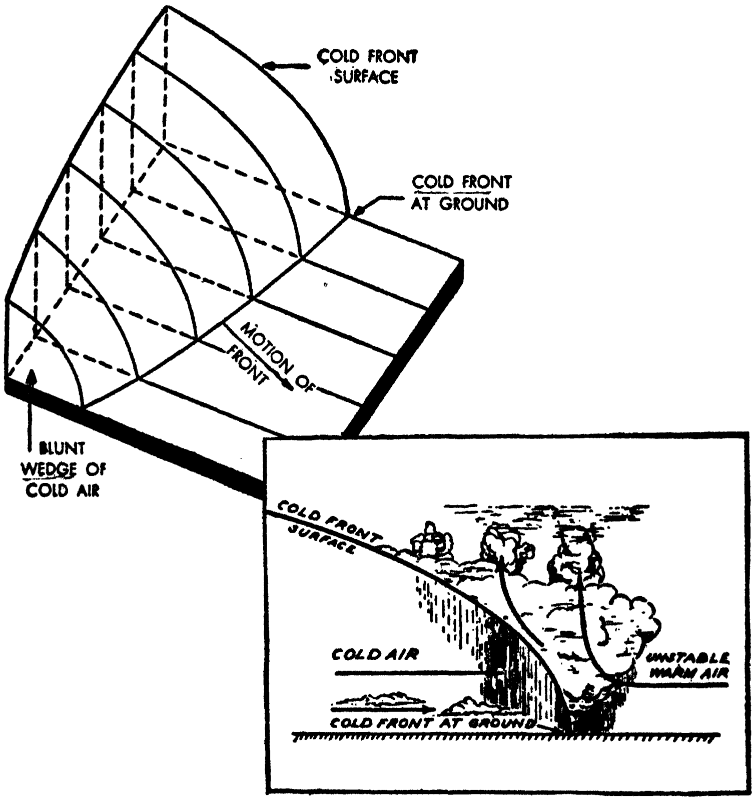


FIG. 108—Upper left: Representation of a cold front; Lower right: Diagram of cold front with unstable warm air ahead

WINDS

As we mentioned before, air currents are set up by warm air rising and cool air descending. These movements may take place over considerable distances, and they may create horizontal air move-

ments as well as vertical ones. Expanding and rising air, and air moving rapidly or in a circular path, may produce areas of low pressure in the atmosphere. Air from areas where the pressure is high will then move toward the low-pressure areas, sometimes with great violence, forming hurricanes or tornadoes. In addition to this source of winds, there are horizontal air currents, the directions of which are affected by the rotation of the earth.

The different angles at which the sun's rays reach the surface of the earth produce ground temperatures that vary all the way from the equator to the poles. The natural difference in temperatures of the air above those areas gives rise to air movements. These movements constitute winds of varying intensity, moving from areas of high pressure and low temperature to other areas of low pressure and high temperature. These winds form a general atmospheric circulation around the surface of the earth. However, they are deflected by the rotation of the earth around its own axis. Since the largest diameter of the earth is at the Equator, the surface moves fastest in that region, the speed gradually growing less toward the poles. The result is that when a mass of air starts to move over the earth's surface, it is deflected to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere. In both cases, it tends to move in a circle, the radius of which depends upon its velocity and its distance from the equator. As a consequence of this, there are five surface wind zones in the Northern Hemisphere, viz:

1. The doldrums of the equatorial zone of low pressure.
2. The north trades blowing from the high-pressure zone at 30N (30 degrees north latitude) to the low-pressure belt at the equator.
3. The belt of calms and light variable winds of the horse latitudes at 35N.
4. The prevailing westerlies blowing between the high-pressure belt at 35N and the low-pressure belt at 60N.
5. The northeast polar winds blowing from the high-pressure area at the north pole to the low-pressure belt at 60N.

In addition to this general circulation, there are what are known as secondary circulations, referred to in meteorology as cyclones and

anticyclones. In this sense, the word "cyclone" does not mean a violent storm or tornado. It means an area of low pressure, with the air moving in a counter-clockwise spiral toward the center. An anticyclone is an area of high pressure, with a clockwise circulation spirally outward from the center. South of the Equator these rotations are reversed.

Measuring the Weather

Several factors affect the temperature and humidity of the atmosphere, and therefore the cloud-forming conditions and precipitation. Among these is the rate at which changes in temperature and humidity take place. This is known as the lapse rate. When air expands without being heated, it grows cooler because of the loss of energy in moving the surrounding air. This is called adiabatic expansion because no external heat is added or subtracted. A good example of this is seen whenever a parcel of dry air moves up a mountain slope. Its pressure is continually reduced, and, because of this pressure reduction, it will expand. Since no heat is given to it, its temperature will be lowered.

In the free (open) air, the volume of the rising air parcel will increase in proportion to the decrease in pressure. And the temperature will decrease at an average amount, known as the dry adiabatic lapse rate. In the case of air which has a high specific humidity (the actual number of grams of water vapor in a kilogram of air), this cooling rate is much slower. This is because the cooling causes the water vapor to condense, and for every gram that is turned into liquid water, 600 calories of heat are given off. This heat warms the air and slows down its cooling rate. The wet adiabatic lapse rate will therefore be much lower than the dry lapse rate—at least in the lower atmosphere. In the higher air, where the temperature and specific humidity are low, the difference is less.

All of these things, then, govern the weather, and they must be taken into account in forecasting what the weather conditions are likely to be within a certain number of hours or days. Some of these phenomena can be seen; others must be detected and measured

by instruments. The basic instruments used by meteorologists are those for measuring the air pressures and temperatures, and for indicating the amount of moisture present.

The barometer is used for measuring atmospheric pressures. In the earliest type, still widely employed throughout the world, the pressure (or weight) of the air is balanced against a column of mercury in a glass tube with its upper end closed. The lower end

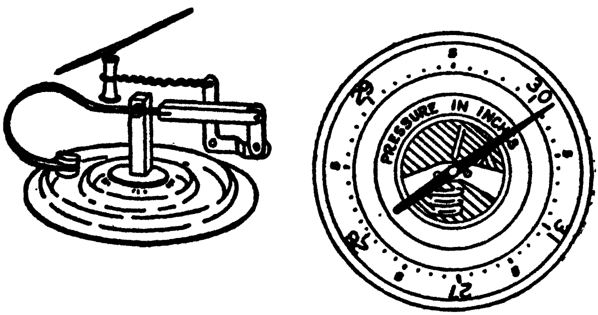


FIG. 109—An aneroid barometer

of the tube rests in a cup of mercury, or its end is turned up and enlarged to obtain the same result. Since there is no air above the mercury column, the column will rise and fall in the tube in accord with the variations of air pressure on the mercury in the cup. At sea level the column will be around 29.92 inches.

Since it would not be convenient to carry the mercury barometer around, another type, called an aneroid barometer, is used. This consists of a hollow metal box or cell, with thin, elastic walls, from which some of the air has been drawn. One wall of the cell is connected with a mechanism which operates an indicating needle over a dial. As the outside air pressure is reduced, the cell (often called the capsule) expands, and as the outside pressure is increased, the cell contracts.

Air pressure is read from these instruments in various units. Sometimes it is recorded in inches of mercury, but modern meteorologists prefer to use millibars—1,000 millibars being equal to 29.53 inches of mercury.

Air temperatures are measured by maximum and minimum thermometers. The maximum thermometer contains mercury and has a constriction in the tube just above the bulb. With increased temperatures the mercury can rise, but falling temperatures cause the mercury column to break at the constriction. The upper part of the mercury column therefore remains, to indicate the highest temperature that was reached.

In the minimum thermometer, alcohol takes the place of mercury. In the tube is a small dumb-bell-shaped glass or steel indicator which can slide along the bore. When the temperature falls, the liquid contracts and its surface tension draws the indicator down. If the temperature rises again, the liquid flows past the indicator, which remains where it was to record the lowest position. Both thermometers can be reset for use by shaking. They are generally hung in a horizontal position inside a special instrument shelter to protect them from the direct rays of the sun.

An instrument used for determining the dew point and humidity of the air is the psychrometer. The sling-type psychrometer consists of two identical thermometers attached to a frame. One serves as an ordinary thermometer, while the other has its bulb covered with muslin, which is wetted. A jointed handle permits the instruments to be whirled rapidly by hand so that the moisture in the muslin evaporates and cools the bulb. The readings of both thermometers are checked against tables. The rate at which the muslin dries depends, of course, on how much moisture there is already in the air. This, in turn, controls the degree to which the bulb is cooled, since evaporating liquids draw heat from surrounding objects, in this case the bulb.

When air is saturated with moisture, the wet-bulb temperature will be equal to the dry-bulb temperature. The difference in temperatures between the two bulbs indicates the degree of humidity. The exact degree is found by referring to a table in which the relation between the two temperatures and the percentage of moisture has been worked out.

When the air contains all the moisture it can hold at its present temperature, it is said to be saturated. Warm air can hold more

moisture than cold air, and as the temperature of the air changes, the degree of humidity changes with it. The temperature to which the air containing water vapor must be cooled (at constant pressure) in order to become saturated is called the dew point. This temperature is important to the plane pilot, because if the temperature of saturated air falls slightly, the moisture will probably form fog or heavy dew. At certain temperatures, that dew may turn to ice on the surfaces of the plane.

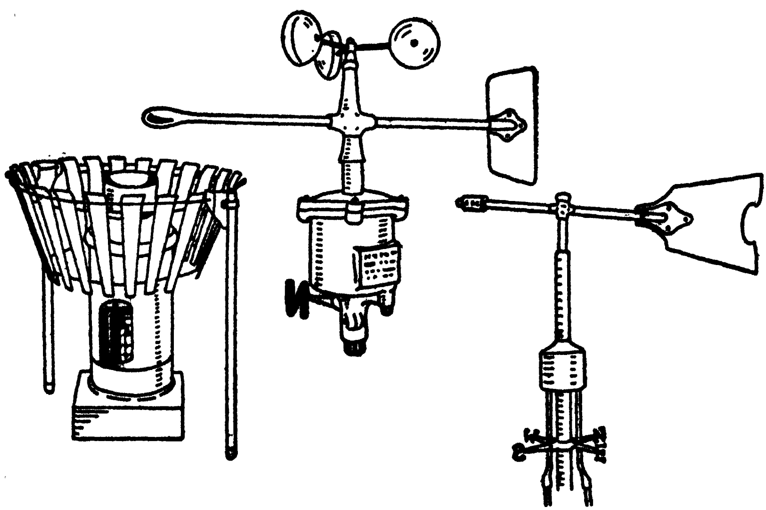


FIG. 110—Left: Snow and rain gauge; Center: Weather analyzer; Right: Anemograph

Another useful meteorological instrument is the rain-snow gauge. This consists of a vertical metal cylinder into which the rain and snow can fall. It has a funnel opening to restrict evaporation. Inside the outer cylinder is a narrower cylinder in which the precipitation collects. This inside cylinder is made one tenth the diameter of the top of the funnel, so that it will multiply the depth of the liquid ten times and make it that much easier to measure. Snow falling into the gauge melts and is measured as liquid, about 10 inches of snow being considered equal to 1 inch of water.

Wind direction is indicated by a simple vane which is automatically turned by the breeze. The movement of the vane is transmitted electrically to a dial or recorder in any desired location. The wind velocity is registered by an anemometer. This is merely three or four hemispherical cups, each mounted on a horizontal arm attached to a vertical spindle so that they will revolve when the wind blows against them and so turn the spindle. The speed at which the instrument revolves indicates the air speed, which is recorded by either mechanical or electrical connections to an indicator dial.

Another instrument which registers the wind velocity through its pressure is the anemograph. This consists of a wind vane, which points into the wind like a weather vane. The arrow point, however, is the open end of a tube in which the dynamic pressure of the wind is built up in proportion to its velocity. This pressure is transmitted through a tube to a recording device. At the same time, the vane movements are recorded, showing the wind direction changes and the frequency of gusts.

In place of the anemograph, another type of wind velocity indicator, using an anemometer with a continuous circle of cups, is used. This multicup rotor does not spin. It is restrained by a spring, so that it can only turn a maximum of 330 degrees at a wind velocity of 100 m.p.h. The readings are transmitted electrically to a recorder.

Air movements are checked by means of small balloons, which are released and their movements followed by means of a theodolite. The theodolite is a telescope, combined with horizontal and vertical scales, from which the angles of movement of the telescope can be read. The positions of the balloons are read from these scales, and since the rate at which the balloon ascends is known (from the comparison of its weight with the weight of an equal volume of air), the wind speeds and directions at various levels can be calculated.

Many other instruments are used, some of them combining the functions of two or more of those described. Some of them incorporate recording devices so that records are kept over long periods of time.

Meteorology of the Airways

Enough has been said to show how vast and complex a subject is meteorology, and how important it is to those who fly. In this country, the Weather Bureau of the U.S. Department of Commerce provides a very complete meteorological service for aviation, and the Civil Aeronautics Administration transmits frequent weather reports by teletype and radio.

At present, there are about five hundred and fifty weather reporting stations along the airways, and another two hundred and fifty or so elsewhere. Airway stations are operated continuously, night and day, sending out hourly reports in code. These codes employ combinations of figures and other characters or symbol letters. All of this information is decoded and recorded on maps by the receiving stations. Here again, symbols are used. The plotting and analysis of charts is an important part of this work, and a necessary study for the student of aeronautical meteorology.

For the pilot and others concerned with the operation of aircraft, it is sufficient to know the fundamentals of meteorology and their meaning in terms of safety in flight. By being able to identify cloud forms and to recognize approaching cold or warm fronts, and to know what these things mean, the pilot and navigator can avoid trouble. No sensible pilot, for example, would fly into a cumulonimbus cloud. Violent internal air currents and powerful electrical charges might well throw the plane out of control, or even wreck it.

Two of the most important ways in which weather can affect flight are, in its influence on (a) visibility, and (b) icing conditions. For safety in flight the pilot should be able to see a considerable distance ahead, as well as vertically. This is important to avoid collision with other aircraft, or with obstructions such as mountain peaks. With an airliner traveling at 175 miles an hour, the pilot has only one minute in which to decide how best to avoid an obstacle three miles away! Therefore, he must not let himself be caught in a sudden atmospheric "blackout."

Fogs and clouds are the principal causes of reduced visibility, but

visibility can also be seriously restricted by haze, smoke, drizzle, rain, and snow. The pilot has to learn to recognize these things before he finds himself in the middle of them, and to understand how they are formed and their probable extent. Visibility is, of course, equally important in landings and take-offs.

The two kinds of icing most frequently encountered are: (a) clear ice, and (b) rime ice. The clear ice is formed when large drops of

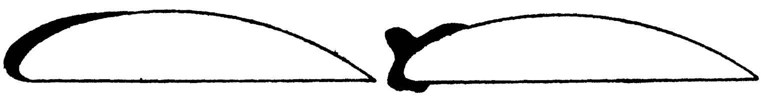


FIG. 111—Left: Clear ice forming on wing leading edge; Right: Rime ice forming

moisture at a very low temperature strike the airplane surfaces. The liquid spreads and freezes instantly, forming a solid layer of transparent ice. Though this ice is smooth and does not altogether spoil the aerodynamic characteristics of the wing, it is very heavy and may make the plane unmanageable because of the excessive weight.

Rime ice is formed when tiny drops of moisture freeze to the surface and to one another. These build up into a white, porous mass on the wing leading edge, destroying its lift. However, it can be more easily removed than clear ice. The clear ice often forms when the airplane is flying through rain which is falling through a freezing layer of air. It is also formed in convection clouds when there are strong, turbulent air currents. Rime ice, on the other hand, will form in thin clouds, such as stratus types, when their temperature is below freezing.

In most cases, rising air currents are necessary to keep the large quantities of water suspended. Icing conditions can therefore be expected in an area of ascending air currents. In other cases, upward currents produced by mountains or warm fronts may also give rise to icing conditions.

When flying through layers of cloud, the pilot has to watch the thermometer. He has also to avoid broken convection clouds, and

fly above mountain clouds. He will probably know that he can fly for no more than ten minutes or so through low-level stratus clouds where icing is likely. When flying over mountains in clouds, through rain or sleet, he will have to watch for ice formation if the temperature is low. To escape icing he can drop below the clouds, providing there is no freezing rain. Or he may climb out of the icing zone if there is not sufficient clearance below the clouds.

If the thermometer does not drop rapidly enough as he climbs, he will know he is probably rising along the discontinuity face of a warm front. Then he will not be able to get out of the icing zone quickly enough, except by flying in the opposite direction. The experienced pilot knows these things, and how to deal with any unexpected weather situation that may suddenly arise.

CHAPTER XII

Signposts of the Air

NAVIGATION might be defined as "the art of finding your way to where you are going from where you started." More elegantly put, it is the art or science or skill of steering or directing a vessel. Quite often it is all three, especially in aviation.

Not so long ago, the navigation of an airplane was a much simpler procedure than it is today. Also, it was a lot less reliable. Then, the pilot flew "by the seat of his pants," following visible landmarks, and sometimes being aided by a simple compass. Nowadays, when planes must fly in all kinds of weather, in darkness as well as daylight, and often over vast stretches of water, or at altitudes where the terrain is invisible, more reliable and practical means of navigation are required.

Actually, there are four different methods of navigation in general use—pilotage, dead reckoning, radio navigation, and celestial navigation. Sometimes two or more of these methods are combined, as the circumstances require. Whichever system of navigation is used, the pilot or navigator is handicapped in a number of ways. Due to the high speeds at which planes travel, small errors in direction may quickly become important ones. The plane is forever influenced by unsuspected air currents which may cause it to drift in any direction, so that drift and compass headings need to be frequently checked and corrected. Due to mechanical defects of the magnetic compass used on airplanes, such compasses cannot altogether be relied upon in maintaining an accurate course or heading. Then, too, although the speed of an airplane through the air can be registered fairly accurately by an air-speed indicator, the actual speed over the ground is more difficult to estimate. Furthermore, the aviator can rarely fix his position by the stars to within less than five miles; more often, it is nearly ten. For these reasons, special

instruments and procedures have been developed which will minimize errors.

In all cases, before undertaking any flight, the pilot should plot the airplane's course, planning, as accurately as possible, the direction he must take and the distance he will have to go. In doing this he will have to use a reliable chart, and make use of weather information supplied by meteorologists, such as the direction and velocity of winds he will encounter, storm areas he must avoid, and altitudes at which he will have to fly to make use of favorable winds.

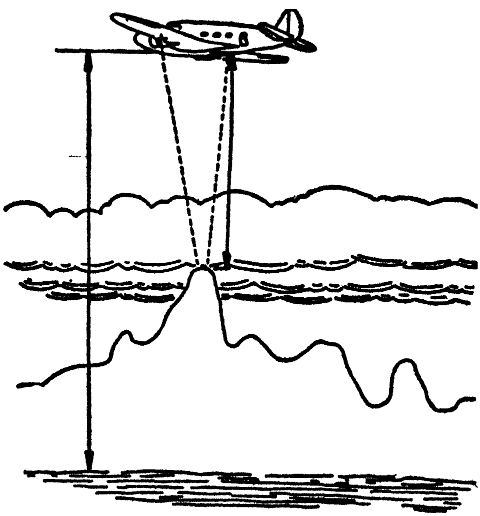


FIG. 112—Action of radar altimeter which indicates height above obstructions

If the distance is short and the weather clear, the pilot can probably make a contact flight, i.e., he can use his compass for general direction and follow landmarks such as rivers or railroads, providing he has an adequate map for reference. In air transport operation, on the other hand, where airplanes must fly on schedule day and night, the pilot must be independent of landmarks. To aid him in this, he has at his disposal instruments which will tell him constantly

how high he is flying, how much clearance he has above obstructions such as mountains, how fast he is flying in relation to the air, the exact direction in which he is headed, how much side winds are causing the plane to drift. Through the use of radio he can learn at any moment his location with respect to radio stations, and he can fly directly along a path laid out for him in the air by a radio beam. Given an occasional glimpse of a clear sky, he can, by using an octant, quickly check his position from the sun or stars. And as he goes, he can record the airplane's track over the face of the earth in the same way that he planned the flight—on that basic navigation tool, the aeronautical chart.

The prime purpose of air navigation is to locate the position of an aircraft with relation to the earth's surface. Therefore, certain points have to be established on the surface from which measurements can be made. The principal points are the two geographical poles, North and South, and the Equator which lies around the center of the earth halfway between them. The surface of the globe is then divided into horizontal sections parallel to the Equator by lines or parallels of latitude. It is further divided into vertical sections by circles or meridians of longitude around the surface passing through the poles.

Actually, latitude is the angular distance, north or south of the Equator, the total angular distance between the Equator and each pole being 90 degrees. The longitude lines or meridians are numbered according to the total degrees they are east or west of the prime meridian ~~which~~ passes through the observatory at Greenwich, England. The maximum distance, east or west, is therefore 180 degrees, or halfway around the earth.

If the parallels of latitude are considered as plane surfaces passing through the earth, they will form circular areas, decreasing in diameter as they get nearer the poles. All of them, except the Equator itself, will be smaller in diameter than the earth. They are therefore called Small Circles. Any other circle formed by a plane section through the earth, which does not pass through the earth's center, is also called a Small Circle.

All of the planes represented by the meridians of longitude pass

through the poles, which represent the axis of the earth. They are, therefore, all equal in diameter to the earth, and so are called Great Circles. Furthermore, any circle on the surface of the earth, the center of which is the earth's center, is called a Great Circle. On the surface of the earth any line which is an arc of such a circle is the

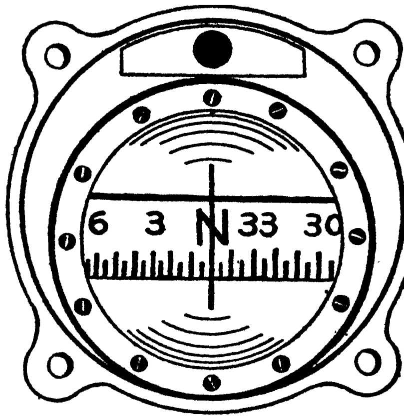


FIG. 113—Magnetic compass

shortest distance between the two ends of that arc. This is important to remember in determining the shortest route from one point to another when laying out a course for navigation.

In addition to the axis of the earth, which is represented by the North and South geographic poles, there are two equally important magnetic poles. The earth itself is a magnet with two ends or poles, one near the North geographic pole, and the other near the South geographic pole. A magnetic compass is a magnetized needle, and one end of this needle will—if it is supported so that it can swing freely—turn toward the North pole. This is called the North-seeking end of the needle. It is therefore used to indicate the direction of the North geographic pole. Since the North geographic pole is not quite the same as the North magnetic pole, the compass direction is not quite accurate. The difference between the direction in which it points and the true North is called variation, and the degree of

variation differs in different parts of the world. An imaginary line connecting all points of equal variation is called an isogonic line. The line along which there is no variation is the agonic line. These lines have been plotted for many areas of the world, including the whole of the United States.

Maps and Charts

The words "map" and "chart" are often used interchangeably in air navigation, but the chart is properly a map on which the course

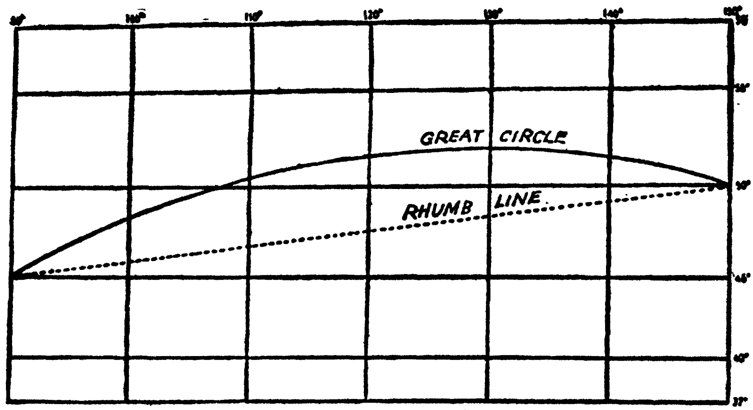


Fig. 114—Comparison of rhumb line and Great Circle line on Mercator chart

will actually be laid out. It is, in effect, a working map, the regular map being used for reference only.

Charts, then, are drawings of part of the surface of the earth. Because the earth is practically a sphere, the surfaces of the land also are curved in both length and breadth. Therefore, it is quite impossible to reproduce the actual shapes and dimensions of these areas on a flat surface such as a chart. There are several methods of representing these surfaces on charts, but on all of them the areas must, of necessity, be distorted. The method, or projection, adopted then depends on the purpose for which the chart is to

be used. The three common methods used in aviation are: (1) the Mercator, (2) the Lambert Conformal, and (3) the Gnomonic projections.

On a chart made by the Mercator projection, all the meridians of longitude are represented by parallel vertical lines, and all the parallels of latitude by parallel horizontal lines. The meridians and parallels cross one another at right angles and form rectangles of equal size for a given latitude. The distance between the parallels of latitude, however, becomes greater the farther they are from the Equator. The higher the latitude, therefore, the greater the distortion, so that it is impossible to use any one scale of miles for the whole chart.

The one big advantage of the Mercator projection is that it is easy to lay out directions on such a chart. Since all the meridians are parallel, the entire top of the chart is North. Therefore, any course laid out in a straight line will cross each meridian at the same angle. Thus the entire course will be at the same angle to the true North. A line such as this, which crosses all meridians at the same angle, is known as a rhumb line. It indicates the compass course to be followed. On a globe, or on charts made by other projections, a rhumb line will be represented by a curve, which makes it difficult to plot positions along it. On the Mercator projection this objection disappears.

On the earth a Great Circle course represents the shortest distance between two points. On the Mercator projection chart a rhumb line would be shorter, and the Great Circle course would be represented by a curve. In long-distance navigation the route would first be plotted on a chart made with another type of projection, and transferred to the Mercator chart, point by point, according to latitude and longitude. The points on the Mercator chart would then be connected by a series of straight lines. The result would be a series of rhumb-line courses approximating a Great Circle route. Even with this manipulation, a fast airplane could hardly maintain a constant compass course for more than an hour at a time. Consequently, the principal advantage of the constant compass course line (the rhumb line) disappears. This is the reason that the Mercator

type of chart is rarely used in navigation, except when a navigator is included in the airplane's crew.

All U.S. aeronautical charts are based on another system of projection, the Lambert Conformal. This projection is particularly suited to air navigation, because distances and directions can be measured very accurately upon it. On these charts the meridians are represented by straight converging lines, and the parallels by parallel curves. In each case, the meridians and parallels cross one another at right angles. The amount of distortion on a Lambert chart is so small that a constant scale of measurement may be used throughout, with negligible error. The locations and areas represented on the chart are therefore in the proper relative positions, and are of the correct proportions and shape.

On such a chart a straight line closely follows the path of a Great Circle, and therefore may be regarded as the shortest route between two points. A possible disadvantage is that a rhumb line (the constant-compass course) will not be represented as a straight line, since the meridians converge toward the top. The angle at which two successive meridians converge is six tenths of a degree. Therefore, a rhumb line will change direction six tenths of a degree for every one degree meridian crossed. This curvature actually is slight, and the plotted line of course can be followed by changing the compass course two degrees for each three degrees of longitude. When flying from west to east, in the Northern Hemisphere, this correction is added. Flying east to west, it is subtracted.

The gnomonic projection is a Great Circle projection, because any Great Circle on the globe will appear as a straight line on the chart. Therefore, the Equator and all meridians will appear as straight lines, though the meridians converge slightly toward the poles. The value of such a chart lies in the fact that any straight line drawn on it indicates a Great Circle course. Such courses can then be transferred to a chart on which the measurements of distance and direction are more readily made. Such measurements are made with difficulty on the gnomonic chart because the line will cross every meridian at a different angle. This also makes it impossible to determine one general course for the entire trip.

Among the charts published by the Government for the use of aircraft pilots are: The aeronautical planning chart, sectional aeronautical charts, and regional aeronautical charts. There are also radio direction finding charts, a Great Circle chart, and a magnetic chart. On the aeronautical planning chart the entire United States is represented in a scale of 1: 5,000,000. Long courses plotted on this chart, or on the Great Circle chart of the United States, are transferred to the regional or sectional charts for use in flight.

Seventeen regional aeronautical charts cover the entire country with a scale of 1: 1,000,000, or about sixteen miles to the inch. They are useful for plotting long flights with fast airplanes because they are less bulky than the equivalent sectional charts. On the other hand, they do not contain all the detail necessary for piloting, and are therefore suitable only for other methods of navigation. They can also be used for planning flights that extend beyond the limits of one sectional chart.

It takes eighty-seven sections of the sectional aeronautical charts to cover the United States. The scale is 1: 500,000, about eight miles to the inch. Each of these charts is identified by the name of the principal city in the area it covers, with some exceptions. These charts contain all the details needed for use in piloting or any other type of navigation.

Each chart is a small-scale representation of a part of the earth's surface, and on it are shown the landmarks and other information of value to the pilot. This information is given in brief diagrammatic or symbolic form. In addition to the symbols, there are a number of unclassified landmarks which are shown as dots with descriptive notes alongside them.

The form and slope of the land and the various altitudes are shown by brown contour lines, and by gradient tints ranging from green at sea level to dark brown at over 9,000 feet. The contours are lines on the ground representing a continuous series of points, all of which are on the same level. They show not only the elevations of the surfaces, but their shape as seen from above, and give the effect of a relief map. Contour lines that are far apart indicate a surface that has a gentle slope. Contours nearer together show

sharply rising ground. On sectional and regional aeronautical charts, each successive contour line represents a rise or fall of 1,000 feet—except in some few instances where unusual local conditions make

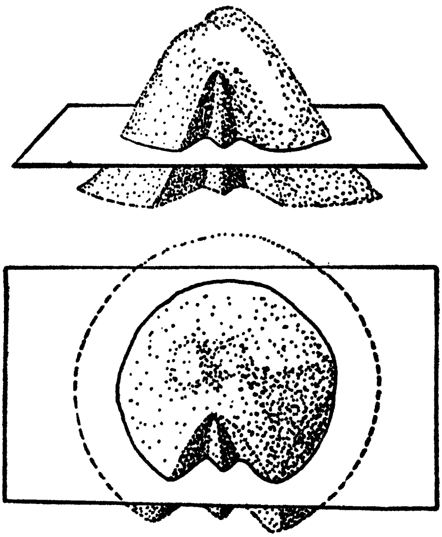


FIG. 115—How contour lines are formed, as shown on charts

it necessary to add intermediate contours showing 500-foot differences.

To all of these things are added such navigation information as airports, beacon lights, radio ranges, and radio identification signals. These are printed in red. In order that the pilot will know what supplies and services he can obtain from any landing field, the fields are classified, and each type has a separate symbol. The elevation of the field is shown in slanting numerals, and the letters "LF" show that it has lighting facilities for night landing.

Two other important items are included on the charts. These are isogonic lines and the compass rose. Isogonic lines indicate places where the magnetic variation is the same. Compass roses, which are merely a circular scale of degrees starting from true North, are

printed at frequent intervals on the chart. They are helpful in approximating courses and bearings.

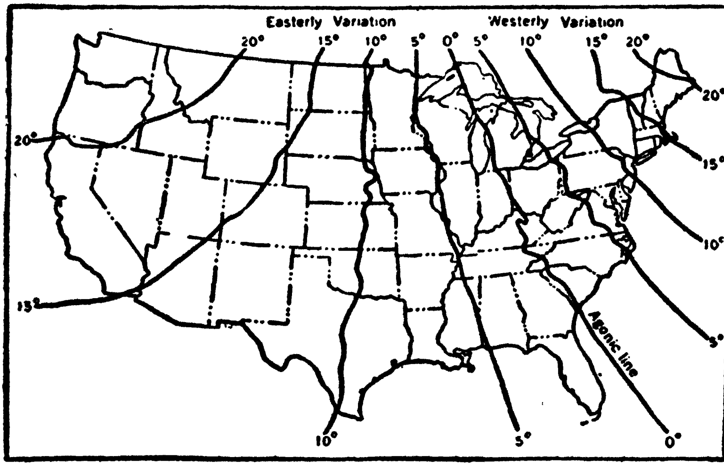


Fig. 116—Lines of magnetic variation for the United States

Navigation Systems

The simplest method of navigation is pilotage. Under this system the pilot has to rely on being able to see certain landmarks such as railroads, rivers, highways, mountains, lakes, church spires, water tanks, towers, etc., with which he is familiar, or which he is able to recognize from a chart. Obviously, this method will be of little use in flying over country which is not accurately mapped, or over large bodies of water, at night, or during other conditions when visibility is poor. On the other hand, pilotage is very often useful as a means of checking a course flown by other methods, and is often used at the termination of flights in approaching the destination.

Simple piloting consists of comparing objects and conformations seen on the ground with those shown on a chart. In a case where the direction of flight followed the general course of a river, it would not be necessary to follow every turn and twist of the watercourse.

The pilot would, instead, fly as straight a course as possible, using the river only as a check. In such a case, where the distances were considerable, he might well combine pilotage with dead reckoning for the short cuts.

Most short, non-scheduled flights are made by this method, which is generally satisfactory, providing thorough preparations are made beforehand. Such preparations consist of selecting the proper charts, laying out the course on them, and studying weather conditions likely to be encountered en route.

The course is laid out by drawing a straight line from the starting point to the destination, on the chart. The route is then checked to see if it is likely to be a safe one, and does not cross large sheets of water or very high mountains, or other territory in which it would be difficult to make an emergency landing. If any of these things is involved, the course is redrawn to avoid them. The course is then divided into ten- or twenty-mile intervals by pencil markings on the line.

The third procedure is to make a note of the most prominent landmarks along the route, and the most striking ones. Special attention is paid to railroads and rivers that may approximate the route. Railroads, which often run long distances in straight lines, are so useful that they are often referred to as "the iron compass." Railroads, too, are usually shown in more or less complete detail, whereas the numerous roads may be only partially indicated, or only the principal interstate highways shown.

Special check points are looked for, such as the intersection of rivers, points at which highways cross railroads, tall structures such as grain elevators, gasometers, forest lookout towers, or striking shapes such as racetracks, etc. It is helpful to tabulate these things according to mileage from the starting point, and the approximate time at which they may be passed over. As an alternative, these data may be noted on the chart itself, in abbreviated form.

Equally important is the check on the probable weather conditions likely to be encountered. At the local airport Weather Bureau office the current weather map can be examined, and other information obtained from the meteorologist, who can also supply data on

wind direction and velocity at various altitudes along the route. These data will enable the pilot to estimate fairly accurately his ground speed and arrival times at check points and destination. As an aid in making this estimate, a diagram is available showing the effect of wind on the ground speed at various air speeds.

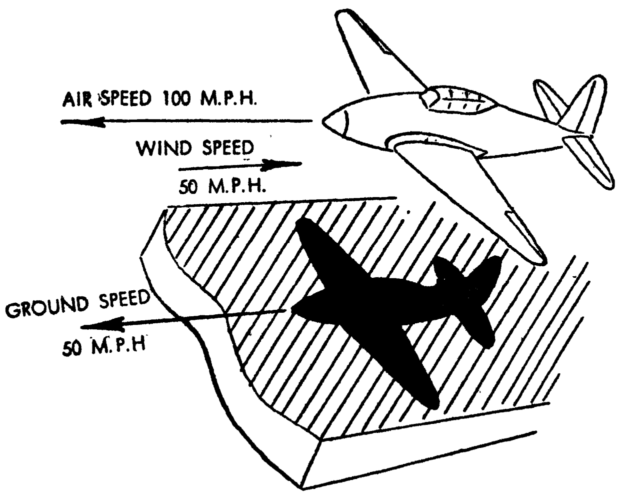


FIG. 117—Comparison of ground and air speeds in relation to wind velocity and direction

Such a diagram will show that, with a direct head wind, the ground speed of the plane will be reduced by an amount equal to the wind velocity. A wind at an angle of 60 degrees to the heading will reduce the ground speed by two thirds of the wind velocity; at 80 degrees the reduction will be one third, and at an angle of 100 degrees, the ground speed will equal air speed.

With the wind at 120 degrees from the heading, the effect begins to be that of a tail wind, increasing the plane's speed by one third the wind velocity, and at 140 degrees it will be increased two thirds of the wind velocity.

In beginning his flight, the pilot circles to the desired altitude and heads toward the first landmark. As soon as that comes in view,

which should be almost immediately, the pilot selects a second landmark on the course which is in line with the first one. By flying the plane so as to keep the two in line, he can tell whether there is any side wind to cause the plane to drift. He notes the compass heading of the plane that is necessary to keep the two features in line, and maintains that heading until the second principal landmark is sighted. Then the procedure is repeated so that the course is constantly corrected. This system is known as steering a range.

Whatever modification of this system is used, the important thing in piloting is to constantly check the course. Even experienced pilots can be hopelessly lost in the air while flying by pilotage once they lose their course, even with many other landmarks available to check their chart against.

Dead Reckoning

Dead reckoning, which really should be written ded reckoning because it is a contraction of deduced reckoning, is the basic method of navigation. It consists of calculating the position from the ground speed and direction or track which have been maintained since leaving the point of departure, or the last known position. It is useful in making flights during which the position cannot otherwise be checked, such as over water. It is often used in conjunction with other methods, and where pilotage will not serve because there are no check points.

Dead reckoning really consists of two separate operations—that done on the ground and that done in the air. On the ground, the course to be steered and the ground speed are estimated. In the air, the errors in the original estimates are determined, and corrections applied for the indicated errors.

As in pilotage, the work done on the ground consists of determining, from charts and other available data, the direction and the distance to be maintained, and the length of time they should occupy. The projected route is drawn on the chart and subdivided in equal distances. The data then needed to estimate the actual course would be: (a) true course, (b) magnetic variation, (c) magnetic

course, (d) compass deviation, (e) compass course, (f) wind direction and velocity. The landmarks would then be noted, together with the distance to each of them from the point of departure, and the estimated time of arrival (ETA).

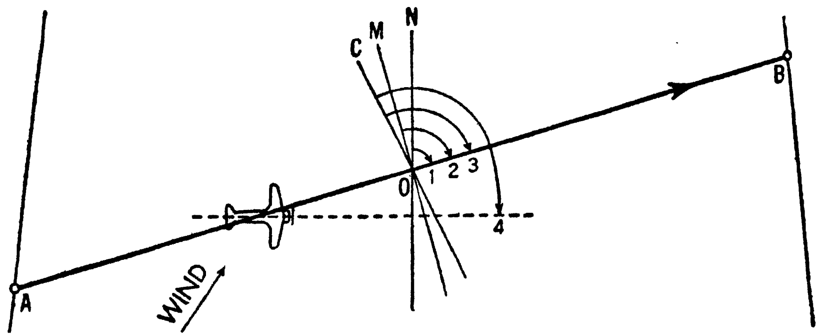
All information regarding the weather possibilities along the route is obtained, such as the likelihood of fogs, storms, or icing conditions. The rest of the work is done in the air, with the help of a variety of instruments, including the magnetic compass, turn-and-bank indicator, and air-speed indicator. An accurate timepiece is the essential fourth instrument, and an aeronautical chart, with a protractor (preferably 360-degree), is also required.

In the air, the job of the pilot or navigator is to keep a record of the direction and speed of flight, obtained from the compass readings and air-speed indicator. These indications have to be constantly corrected, taking into account the velocity and direction of the wind. Because it is necessary to depend on the accuracy of instruments, the skill of the navigator, and conditions in the air, dead reckoning is not always entirely accurate. For instance, the speed and direction of the wind cannot always be accurately gauged, and small errors that creep into calculations are multiplied; and the farther the airplane travels, the greater the possible error. Fortunately, it is generally possible to check position at several points in very long flights, and thus reduce total error to a reasonable amount. It is, of course, a matter of history that numbers of long flights have been made by solo pilots using dead reckoning, with astonishingly accurate results.

In flying by any system of navigation, the pilot uses certain standardized terms for specific directions and speeds. These terms have to be closely adhered to, in discussing navigation, in order to avoid error and misunderstanding. The heading, for example, is the direction in which an airplane is pointing. It may be considered as relative to the true North, the magnetic North, or the compass indication of North. The heading may therefore be the true, magnetic, or compass heading. The opportunities for confusion here are obvious.

The course is the direction in which the plane is required to travel, and this also may be relative to the true, magnetic, or compass North. It is therefore spoken of as the true course, magnetic course, or compass course.

The track is the actual path of the airplane over the ground. If the airplane is flying in a dead calm, or the wind is directly ahead or astern, the track will be the same as the heading. Under other conditions, it will not be the same as the heading. Track also may be true, magnetic, or compass track.



N = True North (geographic meridian)
M = Magnetic North
angle NOM = Magnetic variation (westerly)
C = Compass North
angle MOC = Compass deviation on this heading (westerly)
angle 1 = True Course
angle 2 = Magnetic Course
angle 3 = Compass Course
angle 4 = Compass Heading
AB = Track (or intended track

FIG. 118—The meaning of various terms used in dead reckoning

Drift angle is the angular difference between the heading and the track. The drift is right when the plane is moved to the right by a wind from the left. It is left when the plane moves to the left.

Air speed is the speed of the plane through the air. It is always measured along the heading. The ground speed is the speed of the plane over the ground, and it is measured along the track. Wind direction is the direction from which the wind is blowing, stated relative to the true North. Wind speed is the speed of the moving air relative to the ground.

In determining course and ground speed, required heading, etc., from the known data, the navigator may draw what is known as a triangle of velocities. The triangle is made up of three lines, each of which indicates, by its direction and length, the direction of motion and speed. When two of the lines, representing known factors, are drawn, a line connecting their ends will represent the required

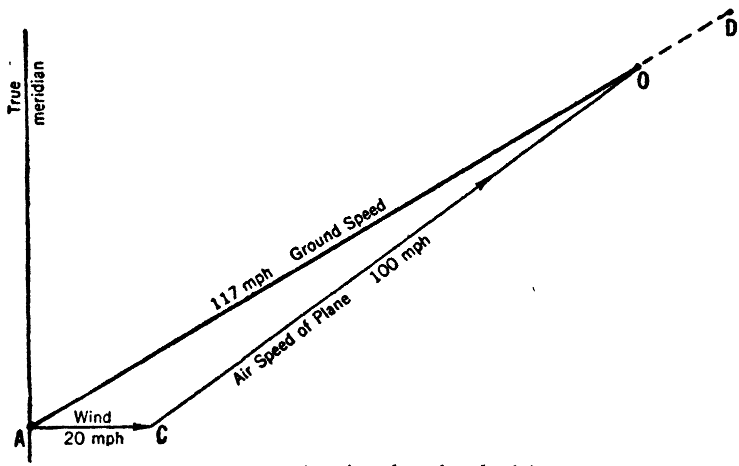


FIG. 119—A triangle of velocities

resultant factor. However, a number of mechanical computers are available, by means of which these problems may be solved without drawing triangles.

In measuring the true course the pilot has to deal with two kinds of directions. On aeronautical charts, the lines representing the meridians of longitude converge toward the top of the chart, as we have already explained. Therefore, any straight line crossing several meridians will cut through each one at a slightly different angle. In flying a compass course the pilot flies the plane in one continuous direction—often called the constant-compass course. This is really the average of all the directions measured at each meridian which the straight line crosses. For convenience, the true course to be flown is always measured at the meridian nearest the halfway

point between the starting point and destination. This angle is measured in a clockwise direction from zero degree at true North to 360 degrees.

Before this course can be flown, several corrections have to be made. The magnetic compass points to the magnetic North pole, and at most places there is a difference between this and the geographic North pole, or true North. This difference is the magnetic variation of the place. If the magnetic North lies to the east of the true North, it is called easterly variation. If it lies west of the North, it is called westerly variation. The magnetic variation is measured at the same meridian as the true-course angle is measured. To determine the magnetic course, westerly variation is added, and easterly variation is subtracted. But this is not all. The magnetic course must be modified to allow for any compass deviation due to influences which prevent it from indicating correctly. This also may be easterly or westerly.

Wind is the main complicating factor in all forms of navigation. Wind is the relative movement between the air and the ground. To a plane in the air, there is no wind except that which it makes itself. The plane moves through the air at its own speed, regardless of whether or not the air is moving relative to the earth. It is only when the pilot checks his position with regard to the ground that the movement of the air becomes obvious.

Any such movement in flight is called drift, and it is measured by means of a drift indicator. In flight, the problem of the pilot is to calculate the true course and distance from the instrument readings so that he can plot them on the chart. This will give him each new position at which the plane has arrived. The first of these factors is the compass heading, which contains the errors of deviation, variation and wind. These now have to be deducted from the observed compass heading so that the true course can be plotted on the chart. This is done by simply reversing the former procedure, deducting westerly deviation and westerly variation. This true heading is corrected for wind in order to determine the track, or true course made good. The observed drift angle is added when the wind is from the left of the airplane, and subtracted if it is from the right.

From the data obtained thus far, the pilot knows the true course made good, the length of time the course was flown, the air speed and the ground speed. This may be plotted directly from the starting point, with sufficient accuracy for all practical purposes. Frequent repetition of this procedure will keep the pilot constantly informed of the airplane's position and what he must do to correct its course so that it will reach its proper destination at the estimated time.

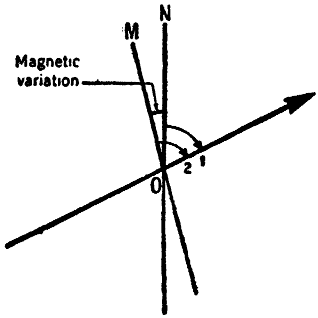


FIG. 120—Magnetic variation

RADIO NAVIGATION

Radio has become increasingly important in air navigation in a variety of ways. It is invaluable in checking positions attained by dead reckoning, as a directional aid when flying along an airway, as a means of enabling the pilot to obtain outside help in establishing his position, and a method of transmitting time signals to aircraft in flight.

Radio aids include radio range beacons, two-way radiotelephone, aircraft direction finders, compasses and homing devices, airway broadcasts of meteorological information and notices to airmen, as well as instrument approach and blind landing aids, including airway markers and airport approach markers.

All these are means of finding position and direction, and, with the other information transmitted by radio to the pilot in flight,

all add to the safety and reliability of flight. They reduce the need for emergency landings due to uncertainty as to weather ahead, enable planes on regular routes to complete a large number of scheduled trips on time, and increase payload by reducing the amount of gasoline required to be carried for weather emergencies.

One way in which a pilot can establish his position is by having two or more radio stations report to him the direction from which his signals are coming. When he receives these bearings from the

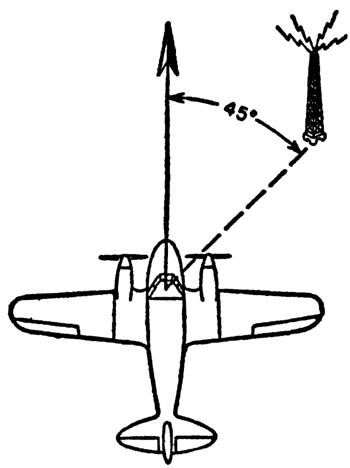


FIG. 121—Bearing of a radio station relative to an airplane

stations, he plots them on his chart and draws bearing lines from each station. The point at which the lines cross is his position. Because of the speed at which the airplane was traveling, and the time taken for several stations to report, such a system would not be very accurate if the airplane maintained its course.

Since an airplane, unlike a helicopter, cannot hover in one position, the next best thing is to circle within a limited area. This can best be done, when over land, by using some landmark as a center. Over water, a smoke bomb may be dropped for the same purpose. If the bearings are to be plotted on a Mercator chart, corrections have to be made. This is due to the fact that the ground waves of

the radio transmitter—which are what the airplane picks up—follow the shortest distance between any two points on the earth's surface. In other words, they follow a Great Circle course, which will appear as a curved line on the Mercator chart, for reasons already explained. The only time no correction need be made for this cause is when the distance between the station and the plane is less than fifty miles.

Airplanes that are equipped with radio direction finders (written D/F) can take a bearing on a station of any kind, which may be a broadcasting station or a radio beacon. The principle on which the direction finders work is that the direction from which radio waves are received may be determined to within 1 to 3 degrees because of the directional characteristics of a loop antenna.

A loop antenna or aerial is a circular coil of wire, usually enclosed in a metallic shell to minimize interference. It may be of the ring (doughnut) type, or covered by a streamlined casing of teardrop form. When the loop is pointed edge-on to the station, the received signal is strongest. When the loop is turned sideways to the station, the signal is at its weakest. For the observation of bearings, the minimum signal is always used because the point of minimum reception is much more sharply defined than the point at which the signals are loudest. This minimum point, at which little or no signal can be heard, is called the aural null.

There are four classes of aircraft direction finders—the aural homing device, the visual homing device, the aural direction finder, and the radio compass. The aural homing device consists of a simple radio receiver with a loop antenna fixed to the outside of the airplane at right angles to the line of flight. This arrangement permits the pilot to take bearings only over the nose or tail of the plane. If bearings are desired from a station to one side of the course, he has to turn the airplane in that direction. But, as long as the bearing is taken from a station ahead, he can keep the nose of the plane pointed toward that station, and "home" toward it like a homing pigeon—hence the term, "homing device."

The aural homing device, as its name implies, brings in the signal to a pair of earphones. An improvement over this is the visual type,

in which a meter dial is substituted for the phones. The signal actuates a needle on the dial to show whether the plane is headed to the left or right, or directly toward the station. In both cases, however, no allowance is made for drift. If the airplane is traveling in a side wind, it will fly in a curve toward the station. It will finally pass over the station headed directly into the wind. To offset this it is necessary for the pilot to determine the wind correction angle, and occasionally check the bearing of the station.

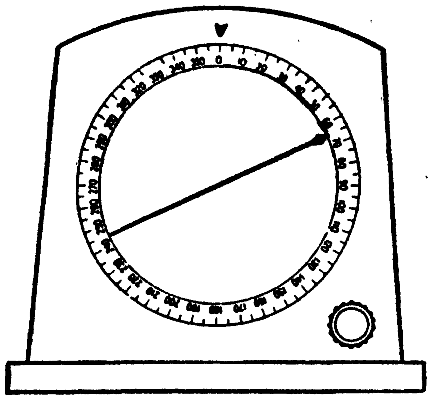


FIG. 122—Dial of an automatic radio direction finder

In an aural direction finder, the loop is rotatable, and incorporates an indicating dial to show in which direction it is turned. In homing with this device, the loop can be turned to allow for drift. The device can better be used, however, by swinging the loop in order to take as many bearings as desired.

There are several kinds of radio compasses, but essentially they are all visual direction finders, or combined aural and visual instruments. Some are automatic in operation and some are not. The automatic type, when once tuned to a station, continues to indicate the direction of that station, regardless of the heading of the airplane. With the ordinary radio compass, the loop has to be manually adjusted to the null position whenever the pilot desires to take a bearing.

The automatic direction finder is free from the trouble, common to other such devices, known as 180-degree ambiguity. This means that while the bearing may be indicated correctly, there is no indication as to whether the airplane is going toward or away from the station. The automatic direction finder does away with this ambiguity through the use of a special "sense" antenna. Obviously, the continuous, automatic, non-ambiguous bearing is of tremendous value to the pilot in solving orientation problems. The relative and magnetic bearings of stations are indicated at all times, and the pointer swings around 180 degrees when the station is crossed. This instrument, however, cannot operate during conditions of heavy precipitation (rain, snow, etc.), or static. At such times, the instrument is switched over to another antenna, which is shielded, and providing a continuous headphone signal. But the freedom from 180-degree ambiguity is lost.

The Radio Range

The purpose of a radio range or equisignal beacon is to transmit radio signals along an airway as a guide to pilots using that air lane. From these signals the pilot can tell his position relative to the airway and to the range transmitting station.

Radio range stations consist of transmitters which send out signals spread over four quadrants of a circle. Two diagonally opposite quadrants send out the Morse signal for the letter A (· –), and the other two the signal N (– ·).

The quadrants overlap at four places, forming four distinct beams in which the signal letters become a continuous hum in the airplane's receiver. If the airplane moves to either side of the beam, one of letter signals becomes gradually distinguishable. The pilot can therefore readily follow the beam. If he knows, from a chart, which beams will bring him to his destination, he can pass from one to the other, identifying each one in turn from its special signals, and so he is independent of any other means of navigation.

These radio range stations are of two types—the loop type and the simultaneous range stations. The loop stations are comparatively

simple and inexpensive, and are operated where it is not necessary to transmit over distances of more than thirty miles. They usefully fill in gaps along airways, mark airway intersections, provide range courses to emergency fields, and act as localizers for low approach procedures at terminal airports.

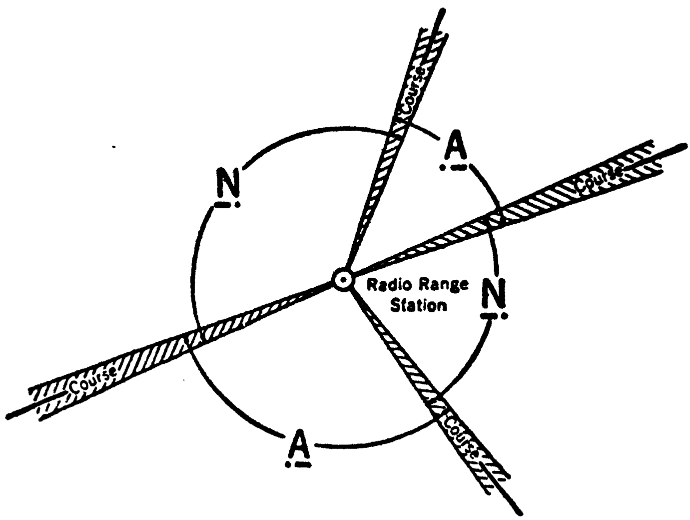


FIG. 123—A typical radio range station

The loop stations were the original type of radio range, and were adequate for daylight operation. But with the increase in night flying, it became necessary to use them after dark when they were affected by the changes in the ionized layers of the atmosphere which produced interference. Most of the interference came from the sky wave transmitted by this type of antenna, which was reflected back to earth and spoiled the ground wave signal. The sky wave was not reflected within thirty miles of the station, so that the system could still be used within those limitations.

Another defect of the loop transmission is that the range signal has to be interrupted when identification signals and weather reports are transmitted. All of this led to the introduction of the simultaneous range stations which can send out range signals and

radiotelephone messages on the same frequency and at the same time.

The loop system employs two loop antennas arranged so that they cross at approximately right angles to one another. A radio transmitter feeds energy, modulated at audio frequencies, first into one loop, then into the other, by means of a motor-driven switch. This is keyed to transmit the letter A, in Morse code, from one antenna, and the letter N from the other. Each signal therefore occupies two diagonally opposite quadrants of a circle. All airplanes flying in one of the N quadrants will receive only the signal N. In the A quadrants the pilot will hear only the A signal, continuously repeated. Along the path where the two quadrants overlap, both signals will be heard, one signal being slightly stronger, depending on which side of the center line the plane is on. If the airplane is flying along the central part of the overlapping area which forms the beam, the signals will merge. All the pilot will then be able to hear will be a continuous hum.

One peculiarity of the loop station is that, above the point where the loops cross, no signal is transmitted in a vertical direction. The higher the plane flies, the wider this area is. From its funnel shape this dead spot gets the name of "cone of silence." It is useful in indicating to the pilot that he is passing over the station.

The newer simultaneous range employs four transmitting masts, one at each corner of a 600-foot square. In the center of this square is a fifth mast, which is used for voice broadcasts. Simultaneous transmission of the code signals and radiotelephone messages is effected by transmitting the signals at a frequency 1,020 cycles higher than the center mast frequency. This difference produces a beat note of 1,020 cycles, which is picked up by the receiver.

To the pilot, the signals from a simultaneous range station sound practically the same as those from a loop station. But, in listening to the voice broadcast from the simultaneous station, he has to use a filter in his receiver to separate the two signals sharply. In the simultaneous range there is no cone of silence.

Each radio range station operates on a different frequency, so that only one should be received at a time. To prevent confusion,

each station has its own identifying signal. With loop stations, the A and N signals are transmitted for thirty seconds, then the station identification signal is transmitted twice, once from each loop.

In flying the beam, the accuracy with which the pilot can detect a fade or increase of signal depends on his training, and his skill in

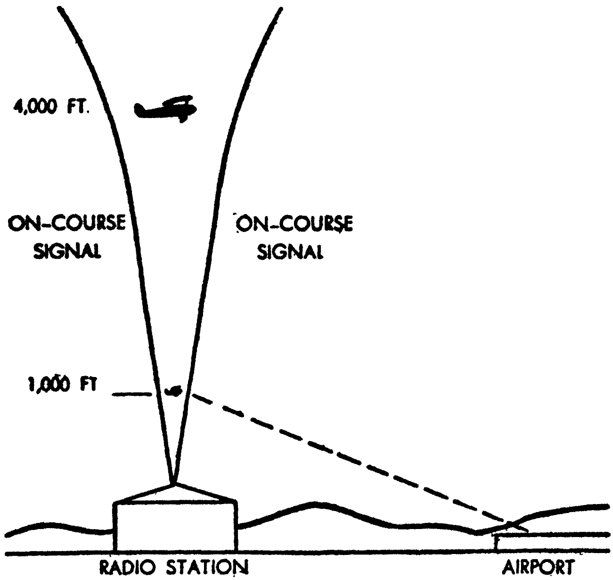


FIG. 124—Cone of silence over a loop range station

operating the manual volume control. An unskillful pilot might well deviate a considerable distance, relatively, on either side of the beam before detecting a change in signal, and thus fly an erratic course. The limits between which an airplane may range to either side of the beam center before detecting a change of signal should not be more than a degree and a half. The courses are plotted on aeronautical charts on this basis. The magnetic bearing of each course, in degrees toward the station, is published for all stations by the Civil Aeronautics Administration, with the magnetic variation specified in each case.

In addition to the radio range station, other transmitters are used as markers. These indicate to the pilot his position along the course. Such markers are of three types—the M, FM, and Z.

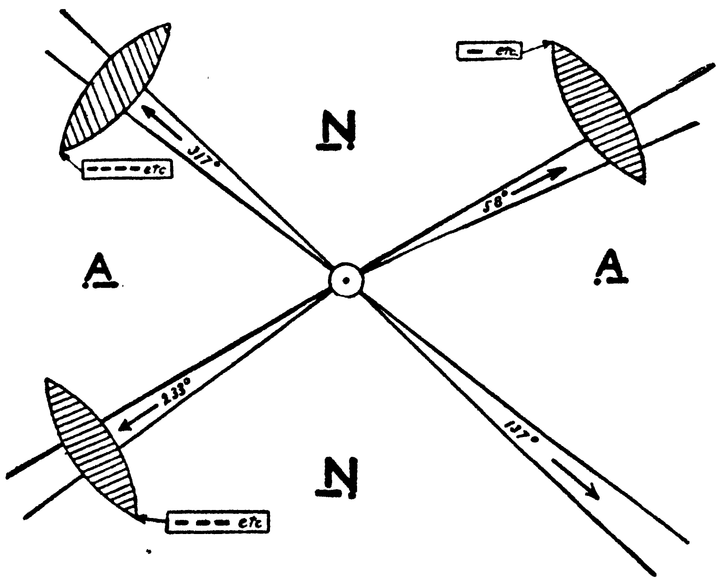


FIG. 125—Fan marker beacons on radio range

The M-type marker is a low-power, long-wave transmitter, operating on the same frequency as the range station on whose course it is located. The signals are received by the pilot, along with the range signal, as he passes near the marker. This signal consists of a repeated single letter in Morse code, and serves only as a general check on position. Provision is made at the marker stations for radiotelephone transmission to aircraft if required.

The FM, or Fan, marker is a 100-watt, ultra-high-frequency transmitter operating on a frequency of 75 megacycles. Its use necessitates a special receiver in the airplane in addition to the regular range receiver. The markers are located along the airway, one to each leg of the range, and radiate in a vertical, fan-shaped pattern

that cuts across the beam. The signal consists of one, two, three, or four code dashes, according to the range leg it is on. The signal is heard in the pilot's headphones, and, at the same time, lights up a signal lamp.

Zone, or Z, markers also are ultra-high-frequency units, and are of low power (5 watts). They operate on the same frequency as the FM so that they can be picked up by the same receiver. Z markers radiate a vertical, cylindrical pattern, and are located inside the loop station cone of silence. While the cone of silence indicates its own position, it does not identify itself, and the Z marker fills this purpose.

The radio range is used as an aid to dead reckoning, and pilots never rely on the range alone. Compasses and other instruments are always used, for there is always a possibility that the range may be turned off, due to mechanical trouble, or become unintelligible because of static interference.

Flying by the Stars

Celestial navigation is the art of determining position on the earth's surface by means of observations of celestial bodies—the sun, moon, planets, or stars. The many errors which may possibly enter into navigation by dead reckoning make it desirable to check the estimated position, based on track and ground speed, from time to time. Radio bearings and celestial navigation form the best practical means for this check when no known landmarks are visible. Radio signals also are not always available, which leaves celestial observations as the only remaining recourse.

The pilot, normally, keeps a record of heading and distance, and, generally, of drift, and can therefore determine his approximate position at any time. This approximate dead reckoning position is used as the starting point from which the celestial observations are worked and plotted on a chart.

A celestial observation consists of measuring the angular distance of a celestial body above the horizon, and noting the exact time at which this reading is taken. The angle is measured by an instrument

—either a sextant or an octant—and the time taken from an accurate chronometer or timepiece. The line of position is then computed

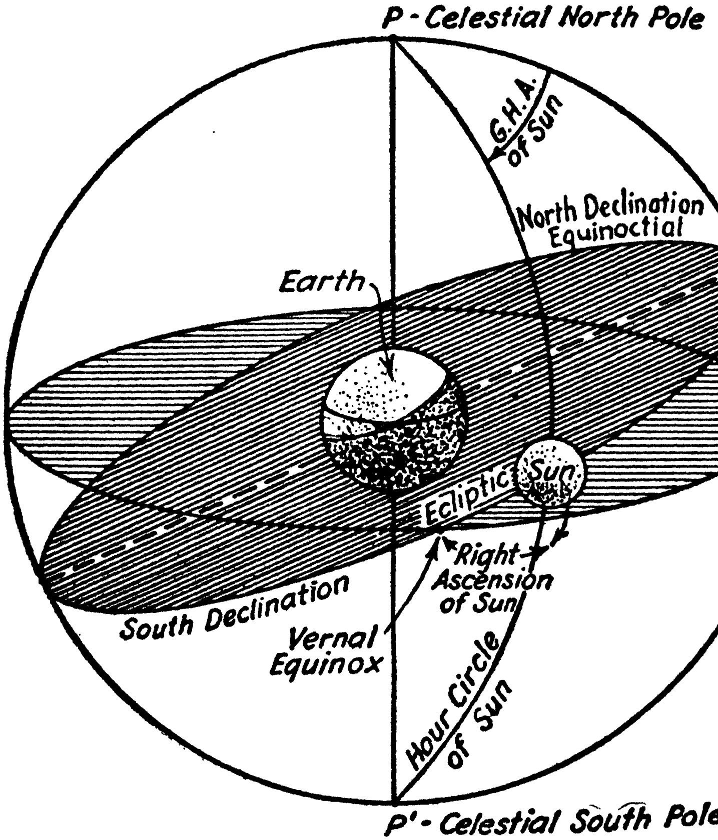


FIG. 126—The celestial sphere, basis of celestial navigation

from the dead-reckoning position, the exact Greenwich civil time, the true measured altitüde, and the celestial coördinates of the observed body taken from the Air Almanac. In the Almanac this information is tabulated in such a form that plotting the position is reduced to a matter of simple arithmetic.

In order to have some means of comparing positions on the surface of the earth with the positions of celestial bodies, these bodies are considered as being located in a celestial sphere. This sphere is an imaginary globe of infinite radius, the center of which is the center of the earth. It can best be thought of as a gigantic transparent globe, with the earth suspended in the center of it.

The geographical poles of the earth are considered as being extended into space to form the celestial North and South poles. The celestial equator, called its equinoctial, also coincides with that of the earth, and the position of the Greenwich meridian is identical. Latitude on the earth is equivalent to declination on the celestial sphere, which is measured in degrees of arc north or south of the equinoctial.

The celestial bodies, except the planets and moon, are more or less fixed in space. The rotation of the earth on its own axis, from west to east, makes it appear as though the celestial sphere rotated in the opposite direction. The earth is therefore considered as being stationary, while the celestial bodies rise in the eastern and set in the western part of the earth's horizon.

The celestial Greenwich meridian is the starting point from which easterly and westerly distances are measured along the equinoctial in terms of hour angle. The distance from the Greenwich celestial meridian is known as Greenwich hour angle, but, unlike longitude, which is measured east or west up to 180 degrees from Greenwich, it is always measured westward up to 360 degrees.

Local hour angle is the difference in longitude between the meridian of a celestial body and the meridian of the observer. It corresponds to the measure of a distance of longitude, and may be east or west of an observer's meridian. Therefore, it cannot exceed 180 degrees. Since there is no fixed point in the heavens to correspond exactly with Greenwich, a point has been chosen which is called the First Point of Aries, or the vernal equinox. This point is the intersection of the ecliptic (the path of the sun) with the celestial Equator in the spring, when the sun is traveling north.

From these corresponding positions on the earth and celestial sphere, the location of celestial bodies with reference to points on

the earth can be calculated by means of mathematical computations. Fortunately for present-day navigators, much of the calculation is reduced to reading tables, while the Air Almanac provides the basic data for observations of the sun, moon, the four brightest

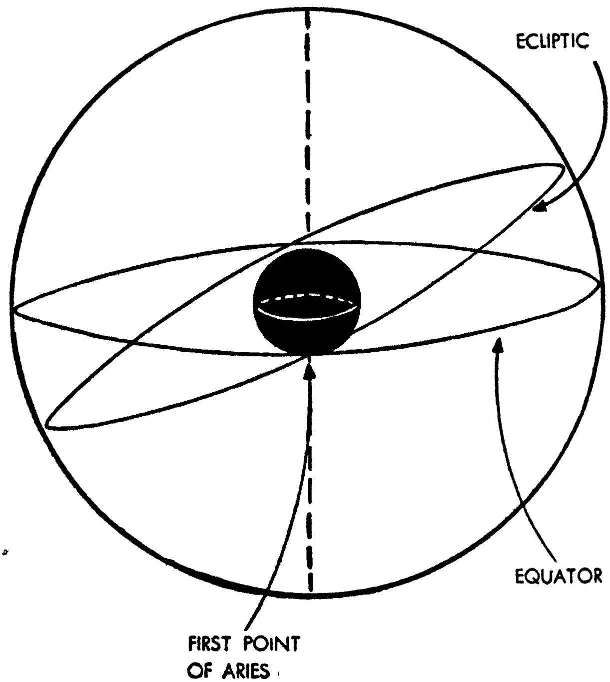


FIG. 127—Celestial equator and first point of Aries

planets, and fifty-five stars. With the aid of a star map, it is easy to identify those commonly used in navigation. The method of calculating the position of the airplane with relation to the ground beneath it, then, is briefly this:

Directly beneath any star, or other heavenly body, is a point on the earth where the altitude of the star is 90 degrees above the horizon. In other words, the star is directly above that point, which is therefore called the substellar point. If the observer moves away

from that point to a distance equal to 10 degrees of latitude, the altitude of the star will be 10 degrees less, or 80 degrees. If a circle is drawn with the substellar point as center, and the 10 degrees as the radius, from all points on that circle the star's altitude will be 80 degrees. This circle is called a circle of equal altitude. It is also the observer's circle of position, because, if an altitude of 80 degrees is observed, the observer must be located somewhere on that circle.

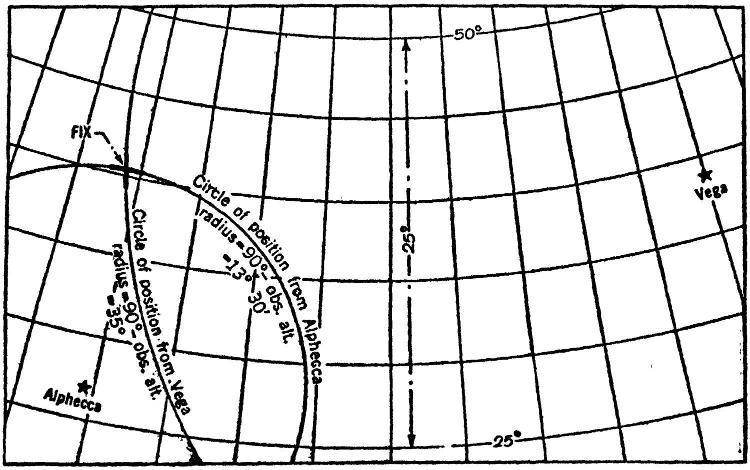


FIG. 128—How two circles of position establish location

Similarly, if the observer moves to a point 20 degrees away from the substellar point, the altitude will now be 70 degrees. What all of this amounts to is that the substellar point is the center of a system of concentric circles of position. As the star moves over the surface of the earth, the system of circles moves with it.

Now the substellar point of that particular star at any instant of time can be found from the Air Almanac. The navigator can then locate it on a small-scale chart, and use it as a center to draw the circle of position on which he was located at the moment of observation. The radius of the circle will, of course, be 90 degrees, minus the observed altitude.

In the same way, the altitude of a second star is observed, and a

second circle of position drawn. Since the navigator is located on both circles, he must be at a point where they intersect. There will, naturally, be two points of intersection, but they are usually so far apart that the navigator can have no doubt about which one is correct. Furthermore, he has his dead-reckoning position with which to check it.

CHAPTER XIII

Flying on Schedule

To MOST people there is a great deal of romance in the spectacle of an airliner speeding through the sunlit skies, or droning by overhead in the black velvet night, its lights twinkling like earthbound stars. It is easy to picture the passengers in their reclining chairs,

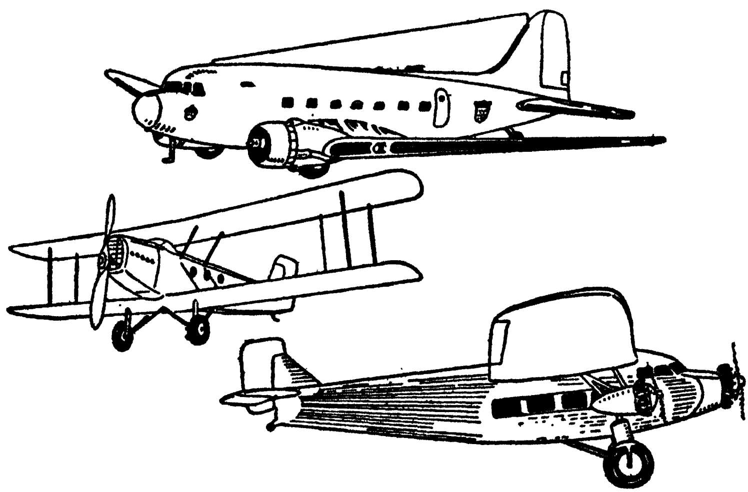


FIG. 129—Above: The famous DC-3 airliner; Center: The 1920 Douglas C-1 air-mail transport; Below: Ford trimotor, the famous "tin goose"

resting, eating a tasty meal, reading, or merely giving themselves up to the enjoyment of the trip, while they watch the miniature landscape glide by ten thousand feet below.

That is modern air line transportation—comfortable, reliable, safe. To keep it that way, to provide a regular service of planes operating on fixed schedules over thousands of miles of airways, calls for far

more than an abundance of gasoline and a supply of skilled young men to handle the controls. From the selling of a passenger ticket to the rebuilding of one of the mighty engines, the range of activities of a modern air line is tremendous.

In the United States there are almost a score of such air lines licensed to carry passengers, mail, express packages, and, in some cases, freight. These lines have at their disposal 43,000 miles of airways over which they carry, in normal times, more than three million passengers a year. In the future, now that the Air Age has arrived, they will carry very many more. Yet, even the case of the biggest of all air lines, this does not mean that they will need great numbers of planes.

Commercial air transportation was really born less than two decades ago. Yet so efficient have the lines become in all phases of

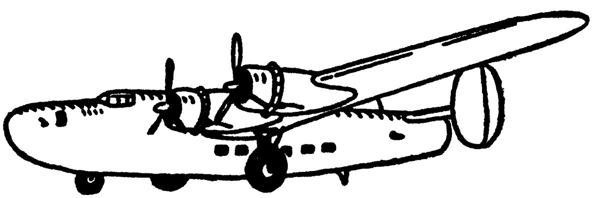


FIG. 130—A modern cargo transport developed from the Liberator bomber

their operations, so well-designed are today's planes, and so skillfully maintained in first-class operating condition, that each plane can pile up an enormous mileage in a year. The speeds at which these airliners cruise also has increased, so that it is no longer remarkable that they each should average a quarter of a million miles a year! Practically all of the major airliners are twenty-one-passenger planes, and one line uses, in addition, thirty-three-passenger stratoliners. And, strange as it may seem, few of them own more than thirty-five planes—yet with them they flew over a billion passenger-miles in 1942—the last period for which peacetime figures are available. From this it will be seen that the key to efficient operation of an air line is to build up the greatest mileage with the smallest

number of planes. Since each twenty-one-passenger plane costs around $120,000, the need for getting the maximum revenue from it will be readily understood.

There is, as may be imagined, much more to the operation of an air line than the flying of the planes. Before a commercial plane can fly, there must be passengers to pay the costs. Beside the airways to fly along, there must be airports from which to alight and to take off from. To keep the sleek liners in perfect condition, there must be inspections and overhauls and repairs. To keep them flying,

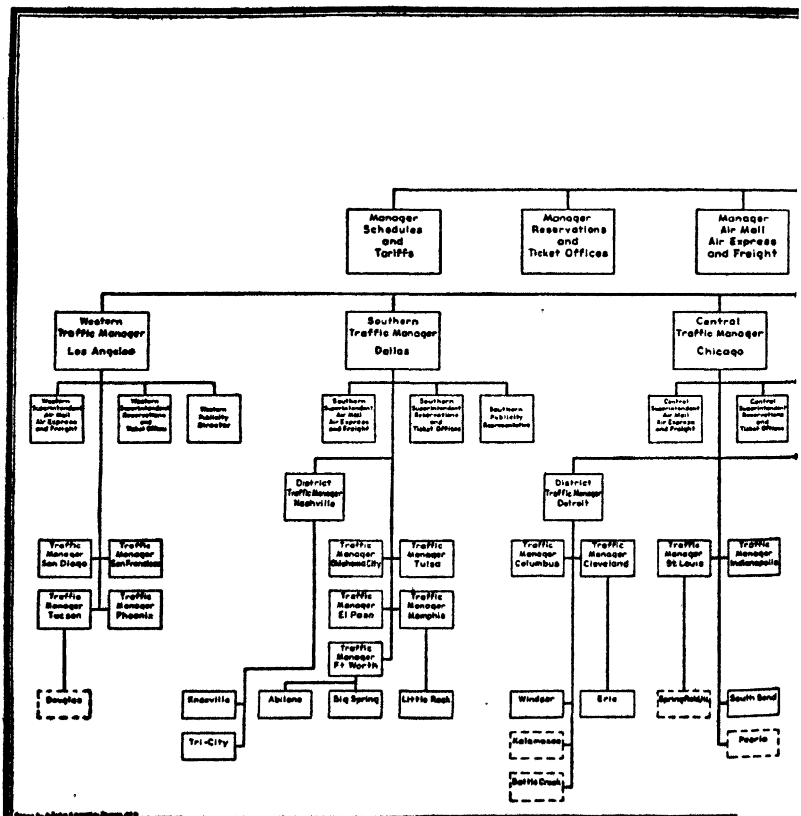


FIG. 131—Organization

there must be supplies and services. So that they may be navigated safely, the weather must be watched and foretold. And all of this means that, for every pilot in the air, there must be ten or a dozen other people on the ground to keep the great ships flying, and to cater to the comfort and safety of those who pay to ride in them. Behind the men and women who work with or about the planes—the mechanics, the commissary and baggage men, the engineers, and washers, and hostesses—there are those others whose chief concern is in the prime source of revenue—the passenger himself—and beyond

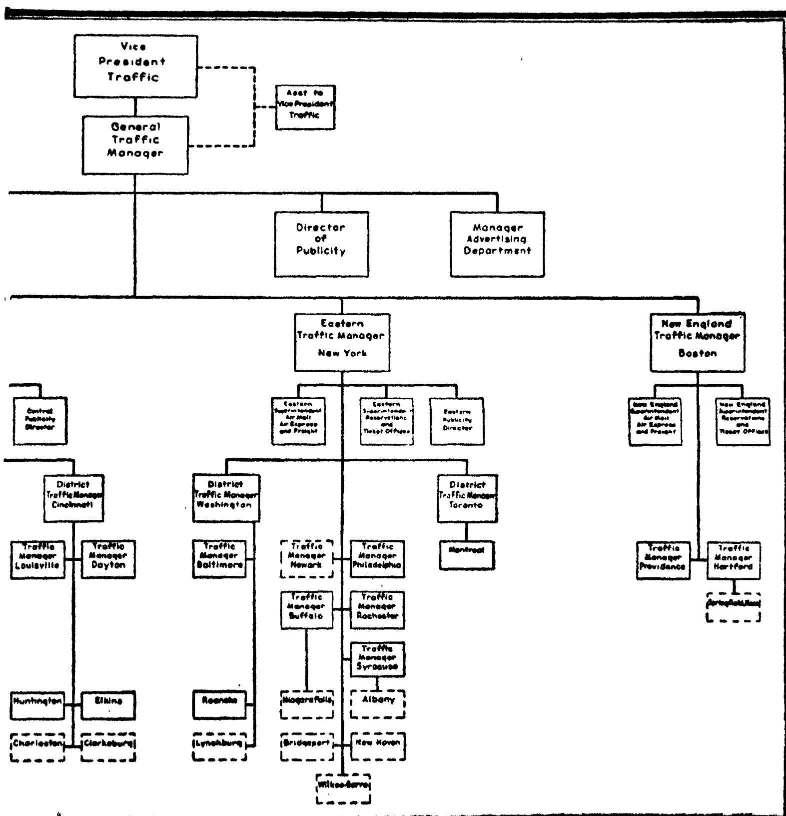


chart of a large air line

them the headquarters organization—the president of the air line, the executives and departmental heads, and the clerical staff.

In a typical air line, these executives and their staffs would form the personnel of four main divisions of the business—general administration, engineering, operations, and traffic. These divisions might, in turn, be split up into various departments, such as communications, station operations, maintenance, flight operations, airports and airways, reservation and ticket sales, air mail, express and freight and schedules and tariffs. In other cases, there might well be an operations department composed of five major divisions—meteorology, communications, passenger services, dispatching, and maintenance.

In the short space available here, it is quite impossible to describe in detail the functions of each department of an air line. The complexity of the organization required, however, and the great number and variety of employees may be well understood if the details of a simple flight are considered.

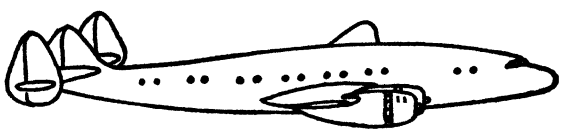


FIG. 132—High-altitude passenger transport, the Constellation

First, there is the airliner itself. Before it takes off, it must have been thoroughly inspected. The engines and all operating gear will have been carefully checked by mechanics to the satisfaction of the pilot. It will have been cleaned both inside and out, and its oil and gasoline tanks replenished with sufficient of lubricant and fuel to carry it to its destination, plus an allowance for emergencies. Probably its interior will have been air-conditioned by blowing cool or warm air through it (according to the season). The apparatus for doing this is an air-conditioning unit, mounted on a truck.

The commissary department will have placed aboard the plane a supply of cooked and fresh food, will have replenished the water tank, the first aid cabinet, and the stock of medical supplies. The

steward or hostess will have checked these, together with the stock of pillows and blankets and other supplies for the comfort of passengers.

Meanwhile, the pilot will have flown the ship "on paper." That is, he will have prepared his flight plan, with the help of a dispatcher. Together, they will have planned the flight by studying all the in-

EASTERN AIR LINES, INC.

TRIP FORECAST

Radio To AGW Radio Preamble LGW

Trip Number and Route Sector 31 33 69 LGAG Date 9/16/45

TERMINAL	Changes in terminal weather expected to occur during the Flight	CLASS
NF BO WA	sctd to ocnly brkn clds abv 5 tsd...vsby abv 4 mi	A
RW	brkn to ovc 3-5 tsd..lite rain starting abt 1000..vsby abv 3 mi	A
GW IS CF	ovc 4-6 hnd with lite rain and lite fog .vsby vrbl 1-3 mi remaining abt same thru afternoon and evening .top of lwr ovc abt 3 tsd	A
GC AG	ovc near 2 tsd with lite rain, lwrng gradually near 8 hnd by 1200 4-7 hnd by 1800 .vsby vrbl 2-4 mi.top of lwr ovc near 4 tsd with higher clds at 6-8 tsd	B

ROUTE FORECAST. Changes in existing weather only. Location and intensity of fronts. Unusual turbulence. Icing conditions, etc.:

hurricane near Lakeland, Fla. moving NNE ward at about 15 mph is xpected to move off coast near DB abt 2000 and continue same course for about 6 hrs thereafter. incrsng lite rain or shwrs in RW-AG sec with cigs 4-8 hnd vsby vrbl 1-3 mi.top of lwr clds at 3-4 tsd with higher clds at 6-8 tsd in same area. surface wnds generally from NE are not xpected to incrse abv 25 mph within nxt 12 hrs.

WINDS ALOFT FORECAST:

RW-CF:	00215	20835	41425	61830	82430	02535
CF-AG:	00215	20835	41430	61520	81725	01825

160600

Meteorologist GALSON Time made: 0600

Radio Operator's endorsement:

Courtesy Eastern Air Lines, Inc.

FIG. 133—Typical radio trip forecast

formation available about the weather along the route. For this information they must rely on the meteorologists of the line. These are the specialists who compile forecasts of weather conditions all along the route of each flight. They base these forecasts on reports received from the line's own meteorological centers, and from some of the five hundred government weather stations throughout the United States.

Such reports are received at all the airports served by the air line by teletype, and the information is at once transferred to weather maps by the meteorologists. If any important changes in the weather occur during the flight, the pilot will be informed of them by radio.

If it is possible to fly, the pilot will prepare the flight plan, which will tell the altitudes at which he proposes to fly over various parts of the route, the speed to be maintained, and the approximate times at which he expects to pass over certain check points, and the time of arrival at stops and destination.

When the pilot and the dispatcher have agreed on the flight plan, it is sent for approval to the division flight superintendent or chief pilot. The chief pilot checks the weather estimate, the wind velocity and direction, the best altitude to fly, the compass headings, the power output of the engines necessary to maintain the schedule, etc., with the dispatcher and the air line meteorologist. He knows, from other sources, the condition of all airway's equipment, and airports throughout the line of the proposed flight. He has accurate estimates of the quantity of fuel which will be required, making allowances for head winds, with a reserve, in case conditions make it necessary for the ship to fly to an alternate landing field.

After that, the flight plan is finally approved, or modified by the C.A.A.'s traffic control, which allocates flight altitudes to all commercial planes flying the same routes.

This flight plan, in addition to contributing to the safety and efficiency of the operations, has a further use. The plans are filed for comparison with the flight logs of the planes, and so enable the management to check the performance of the plane and engines. This has a bearing on the amount of gasoline carried, which, in

turn, affects the possible payload, and therefore the costs and revenue.

In this way, every flight is cleared from the airport by a dispatcher, but only after the weight and loading of the plane have been

Form 52 Rev.-8-44

EASTERN AIR LINES, INC.

TERMINAL & INTERMEDIATE CLEARANCE

1. TRIP ________ (Number — Date of Origin) AIRPLANE NO. ________ (EAL) LICENSE NO. NC- ________ (CAA) STATION ________ DATE ________

2. Permission is hereby granted for above trip to proceed in accordance with following clearance issued by authorized Dispatcher, subject to Captain's discretion.

Dispatcher ________ By ________

3. A complete report of observed weather from approved sources compiled within the last 1½ hours is given on the reverse side of this clearance.

4. FUEL AND OIL SUPPLY ABOARD:

Tank	Gasoline	Oil
Left Main		
Right Main		
Left Aux.		
Right Aux.		
Total		

5. BAROMETRIC PRESSURES.

	Station	Time	Reading Ins Mercury	Altimeter Number
Field Pressure				1
Altimeter Setting				2

6. SPECIAL INSTRUCTIONS:

7. I hereby certify that the information on this form is correct to the best of my knowledge and belief.

Station Manager ________ By ________ Time ________

8. I hereby acknowledge receipt of the foregoing clearance, including weather report and consider conditions suitable for the scheduled flight, and will conduct the flight in accordance with procedure outlined in Operations Manual and in accordance with the attached Flight Plan, or Flight Plan previously filed at ________

Captain ________ Time ________

9. Orders Received in Flight:—To Flight ________ From ________ Time ________

Dispatcher ________ By ________

Courtesy Eastern Air Lines, Inc.

FIG. 134—Terminal clearance form

checked. The total load that the plane can carry is fixed, and must never be exceeded. The payload, which consists of the passengers, mail, and freight, can only be increased by reducing the weight of gasoline and oil carried; and this is not always possible. The amount of fuel carried is limited to the actual requirements of the flight—the tanks are never just filled. This matter of weight is the reason why every passenger and every piece of baggage must be weighed.

While these things are being done, the baggage handlers are busy loading the plane with the mail and express matter, carefully placing them, and lashing the pieces whenever necessary, so that they cannot move in flight.

It is an interesting fact that a plane can be allowed to take off with a greater load than is permissible in landing. This is because of keeping within a certain maximum the impact with which the plane might strike the landing runway, and the length of run within which it can safely be landed and stopped. As the gasoline is used up during the flight, the weight becomes less and makes up the difference. If sufficient gasoline is not used up, the pilot has to dump the balance before he lands. All of these things, of course, add to the work to be done and the number of people required to do them.

Up to this point, the plane is ready for the take-off, except for the mere detail of the passengers. But there will be no delay on this score if the passenger service department has done its work. This end of the business—the selling of the tickets and making the reservations—is handled by ticket sellers in city offices and at the airports, as well as by independent agents. Telephoned bookings may be handled by reservation clerks at the air line offices. Some of the larger airliners have as many as two dozen girls engaged in this work day and night—in normal times.

However big or small the air line, this making of reservations is a complicated business. It is often far more work than just entering an order for a seat. If the passenger is traveling a considerable distance, it may not always be possible to arrange for him to have a seat on the same plane all the way to his destination. This may have to be

checked with offices at other airports along the route, and special arrangements made for transfer to another plane. In other instances, the way stations may be called upon to fill otherwise empty seats for part of the journey. And in every case, each station en route must rely on the others before it for full information as to seats available and to what points.

Another branch of the passenger department concerns itself with the passenger agents and ground crews at the airports. Members of the ground crew supervise the handling of the mail, express, and passengers during the time the plane is being loaded. Their work includes all the details of checking tickets, weighing, making out manifests, checking the cargo lists, and seeing that the plane is properly and accurately loaded.

Stewards and hostesses are included in this group. Their duties are to check the passengers against the lists as they board the plane, and see that they are directed to their seats. When the plane is ready to take off, they see that all passengers are comfortable, and that their seat belts are fastened. They give the passengers gum to chew to relieve the effects of altitude, and ear cotton if they wish. They put their passengers at ease by chatting with them, provide them with papers and magazines to read, point out the scenery, and serve meals as required. In flight, the ordinary twenty-one-passenger air-liner, such as the Douglas DC-3, carries a crew of three, pilot or captain, copilot, and steward or hostess.

Keeping the Airplane Flying

Of equal importance with the organization of the traffic is the maintenance of the planes in perfect operating condition. This also is work undertaken by the air lines themselves, and, in spite of the comparatively small number of planes involved, accounts for a large proportion of the total payroll. At the air line's main base there are extensive maintenance shops, where complete overhauls of the planes and their power plants are carried out every few thousand flying hours. Frequent inspections also are made here, and at other specified airports, where the company maintains hangars and shops

equipped for minor repairs and replacements, as well as for replenishing the gasoline and oil of the big transports.

At the terminals from which they operate, the planes are given a daily flight check, in addition to other periodic inspections. This is part of the plan of *preventive* maintenance—catching the trouble before it develops into something serious. Other and more complete inspections are carried out after a certain number of hours of flying time, as specified by the C.A.A. Some of these are really complete and thorough.

Daily inspections involve only those parts that can be seen and easily got at. The others necessitate the disassembly of more and more units until every working part of the plane is checked. Very little is ever done to parts in the way of major repairs. When such are needed, the part or unit is generally replaced with a new one. With the careful adjustment given at frequent intervals, breakage and excessive wear are forestalled. Through complete overhauls every 5,000 to 6,000 hours, the equipment is put into practically new condition. This is only possible by doing all maintenance work to factory standards, with fits to a ten-thousandth of an inch or less.

When the time for a complete overhaul arrives, the airplane is practically taken apart. The wings and all control surfaces, including most of the tail, are removed. All seats are taken out and the flooring is lifted. The landing gear is taken down and every enclosed space is opened up, so that all controls, control cables, hydraulic lines, and all moving parts are exposed. Every rivet is examined, and damaged sections of the skin are replaced. The engine is likewise stripped down, until no two parts are left assembled. Each small shaft, spindle, bearing, or gear is measured for wear. Every item is thoroughly cleaned and checked for flaws. When the engine is put together again, it is every bit as good as new. Every instrument is tested and taken apart in a special instrument shop, which is air-conditioned so that the test conditions are always the same. Nothing is left to chance in any part of the plane, and when it is reassembled its performance should rate one hundred per cent.

This work calls for not only the most complete range of machine tools, gauges, and test equipment, but an extensive staff of mechanics

skilled in a wide variety of operations. Unlike a manufacturing plant, there is no great volume of repetitious work or mass production of any item. The mechanics must therefore, for the most part,

Form 208 (Revised 7-45)

DOUGLAS FINAL PLANE CHECK-OUT REPORT

GENERAL

Time Check-out started ______ m. Inspection and work sheets signed ______ Log book signed ______

COCKPIT

1. Cockpit hatch made fast
2. Cockpit windows clean
3. Floor boards secure
4. Hydraulic fluid supply reservoir to proper level
5. Pump up landing gear—flaps retracted
6. Windshield wiper, check for leaks, pressure ON
7. Flettner indicators in neutral
8. Move all flight controls ______ Observe movement
9. Check Flight Panel Mountings
10. Nose valve in fully closed position
11. Operate cross feed valve several times
12. Field altitude, gas cost and cockpit check list
13. Power chart, radio and operations manual
14. Cockpit safety belts
15. Engine Lux full and control neutral
16. Hand Lux sealed
17. Glycerine bottle full
18. Carburetor Deicer Tank full
19. Other Deicer Tanks full. (If Deicer boots installed)
20. Fourth crew seat assy. and safety belt
21. Airway maps in place and sealed
22. Tool Kit complete and sealed
23. Spare Hydraulic Fluid can full
24. License, CAA Load'g Chart, A&E Limits, Warning Placards
25. Bag Straps, Compt. 1 ______ (2): 3 ______ (2): 4 ______ (2):
26. Oxygen pressure ______ lbs. sq. in. at temp. of ______ °F.
27. Oxygen equipment and supplies
28.

CABIN

30. Check No Smoking and seat belt sign
31. Steam Heat control in proper position
32A. Check reading lights ______ chime
32B. Seat Adjusting mechanism and safety belts serviceable
33. All rugs in place and secured
34. Emergency doors safetied (0625 Alum. 26-1186)
35. Spare seat back equipment in 7R pocket
36. Hand Lux sealed
37. Buffet Switch Panel functions
38. Cabin door key in place
39. Entrance Light at Door

LAVATORY

40. Lavatory Door Lock Operative
41. Lavatory Light and Chime Signal
42. First Aid Kit Sealed
43. Check wash basin and drains for leaks, stoppages
44. Disinfectant in Master Can
45. Assist handle secure

REAR BAGGAGE COMPARTMENT

50. Operation of rear baggage compartment door lock
51. Compartment clean
52. Baggage straps in place (2)
53. Tail Tie down cable
54. LG safety pins in pocket
55. Refuse Bag secure

INSIDE OF TAIL

60. Cables safetied
61. Flares safetied (.0159 soft coper-24-2714)
62. Check for loose rags, etc.
63. Check tailwheel lock device
64. Installed shear pin and spare
65. Rudder check cables

OUTSIDE TAIL

70. Flare Port Covers
71. Tail Wheel safetied (bolts)
72. Tail strut proper height
73. All Access doors in place and secure
74. Flettners safetied
75. Ground cable serviceable
76. Master Can door safetied
77.

WINGS

80. Wing Bolt Fairings safetied
81. Ailerons intact
82. Flettner intact and safetied
83. All Access doors in place and secure

LANDING GEAR—NACELLES—ENGINES

90. Engine mount cowling safetied
91. Engine cowling safetied
92. Cowling clean
93. Props and governors safetied
94. Nacelle inspection doors secured
95. Tires and brake drums
96. Struts proper height
97. All strut bolts safetied
98. Engine oil drain plugs Okay: L ______ R ______

FUSELAGE AND CENTER SECTION

100. Fuel strainers safetied
101. All access doors in place and secure
102. Nose door closed and safetied
103.

ENGINE RUN-UP CREW

110. Check operation of engines
111. Check hydraulic pressure-run up
112. Check operation of instruments
113. Check operation of propellers
114. Check operation of engine controls
115. Check operation of instrument lights
116. Check operation of all warning lights
117. Check operation of all deicers
118. Check landing lights — navigation lights
119. Cross feed valve off
120. Hydraulic sytm. [illegible] valve in closed position and safetied
121. Vac. Pump selector valve on proper engine
122. Hydraulic pump selector on proper engine
123. Boiler water can full

Courtesy Eastern Air Lines, Inc.

FIG. 135—Typical plane check-out report

be prepared to undertake jobs involving machine tool work, sheet metal working, welding, or even the sewing of fabric on control surfaces.

All of this means, beside a vast investment in equipment, the long and careful training of mechanics, many of whom start as apprentices, having to be taught everything they know. And that is a sizable investment in itself. According to C.A.A. regulations, the mechanics are divided into two classes—airplane mechanics and airplane engine mechanics, and they are licensed as such. For many of the jobs in air line shops a man must have both certificates—which means that he must be trained in all phases of maintenance, and, in addition, have a year's experience in the shops.

The maintenance division of a large air line, therefore, may employ several hundred mechanics and foremen at its base shop, beside the supervisory staff.

Then, too, keeping track of all these things is a sizable job in itself. Careful records are compiled so that the history of every engine, propeller, battery, radio, and instrument is known from the time it was received from the manufacturer. Its behavior, its defects, the number of inspections, the overhauls it has received, the parts that have been replaced or repaired, the ships it has been used on, the mileage it has flown—all these things are known, and keeping these records is a business in itself, which calls for a substantial clerical staff.

Outside the hangars, there are other jobs for the mechanics to perform. They have to drive the tractors that move the big ships from the hangars for testing—starting the engines inside the hangar would blow everything out of the place, so strong is the propeller blast! These tractors, too, may move airplanes to loading position on the ramp, or tow disabled ones to the shops. Other men are responsible for "gassing" the planes—driving the gasoline truck, testing the gasoline, and filling the tanks. Some of them form special crews for the crash trucks, which are equipped to handle any kind of accident, from a nosed-over light plane to a burning wreck. Another mechanic wheels a battery cart out under the gleaming nose of the plane to start the powerful engines and save the ship's batter-

signal ordinarily is ten miles in daytime and fifteen miles at night. The instructions transmitted by a light signal are limited to approval or disapproval of a pilot's anticipated actions and the general warning signal which advises the pilot to be on the alert.

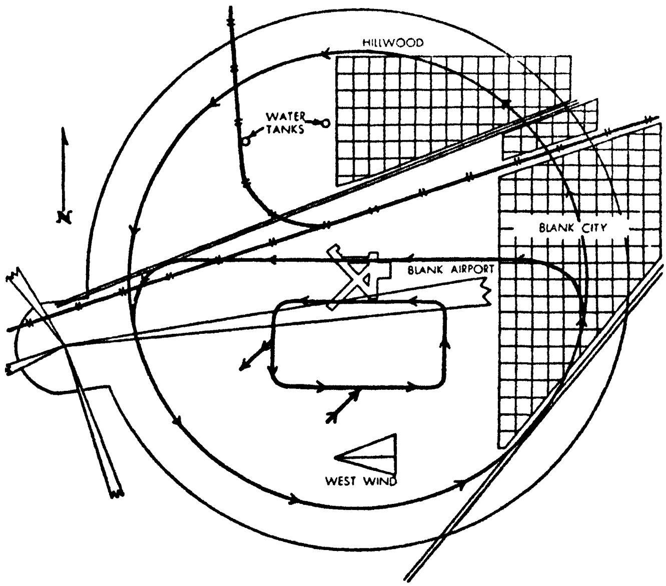


FIG. 138—Traffic pattern for west wind in control zone

When an aircraft is in flight, a green light will mean "cleared to land." A red light will mean "give way to other aircraft and continue circling." During darkness, a pilot wishing to land should turn on a landing light as he approaches the airport, unless he has already been given a green light. A series of flashes of a landing light by the pilot intending to land will mean: (a) if the floodlight is on, the pilot wants it turned off; (b) if the floodlight is off, he wants it turned on. Pilots should acknowledge light signals by rocking their wings during daylight, or blinking their landing lights during darkness.

When an aircraft is on the ground after dark, a pilot wishing to

attract the attention of the traffic controller should turn on a landing light, and taxi the aircraft so that the light is visible to the controller. The landing light should remain on until signals are received from the tower.

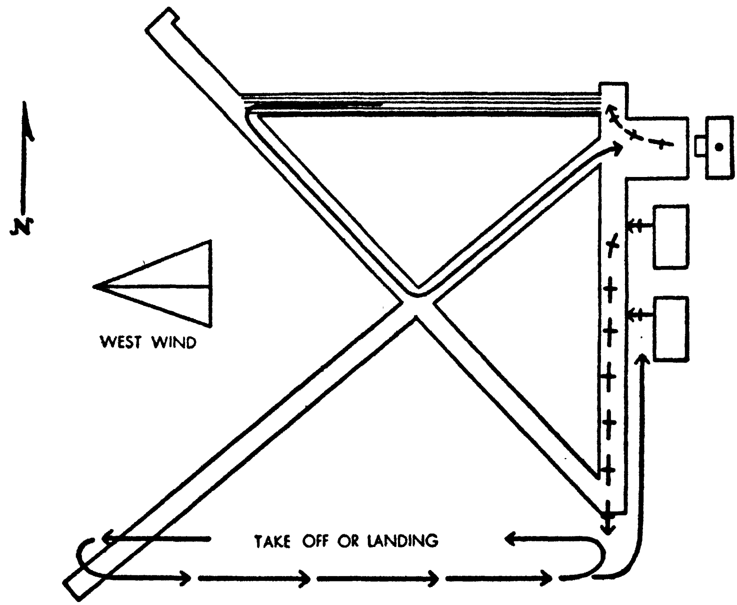


FIG. 139—Taxi pattern for west wind

When a pilot is taxying, a red light signal will mean "stop." A series of red flashes will mean that the pilot is to taxi back to the hangar line. A series of green flashes will mean "cleared to continue taxying."

When a pilot is in a position for take-off, a red light signal will mean "clear the runway immediately, and wait." A green light will mean "cleared for take-off." During daylight, pilots should acknowledge light signals by moving the ailerons or rudder, and, during darkness, by blinking the landing lights.

Alternating red and green flashes will be a general warning signal to the pilot to be alert for hazardous or unusual conditions. During

night or day, flashing lights outlining the traffic direction indicator (tetrahedron, wind tee, etc.), will mean that flying in accordance with contact flight rules has been suspended. At landing areas not equipped with a traffic direction indicator, the lighting of the rotating beacon in daylight will mean the same thing. A flashing amber light on the control tower will mean that a clockwise flow of traffic is required.

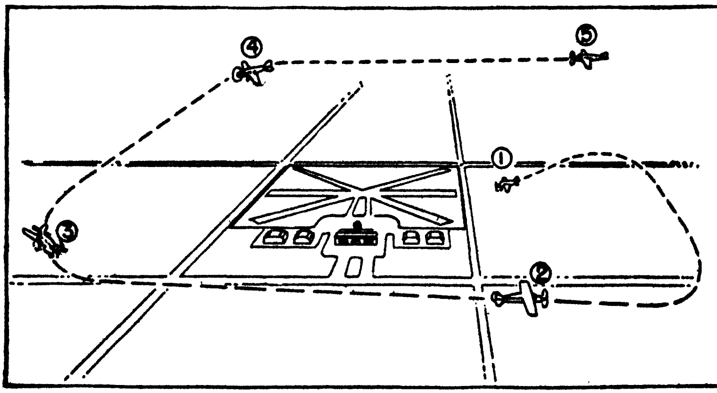


FIG. 140—Position of aircraft in a traffic pattern

When an aircraft is forced to land at an airport at night, it shall signal, by means of a series of short flashes, with its navigating lights.

RADIOTELEPHONE COMMUNICATION

The following phrases and procedures shall be used in all radiotelephone communications with ground stations. A uniform flow of language is necessary in order that each word may be heard distinctly. The position and distance of the speaker from the microphone should not be changed during transmission. Each syllable of each word should be enunciated clearly and distinctly.

Control towers shall be identified by the name of the station, followed by the word "tower," as, for example, "Chicago Tower," "Washington Tower," etc. C.A.A. airways communications stations

shall be identified by the name of the station, followed by the word "radio," as, for example: "Cleveland Radio," "Pittsburgh Radio," etc.

Aircraft shall be identified during radiotelephone communications in the following manner: Itinerant Civil: (Make)—(certificate number), for example, "Stinson one, two, three, six, five"; "Waco

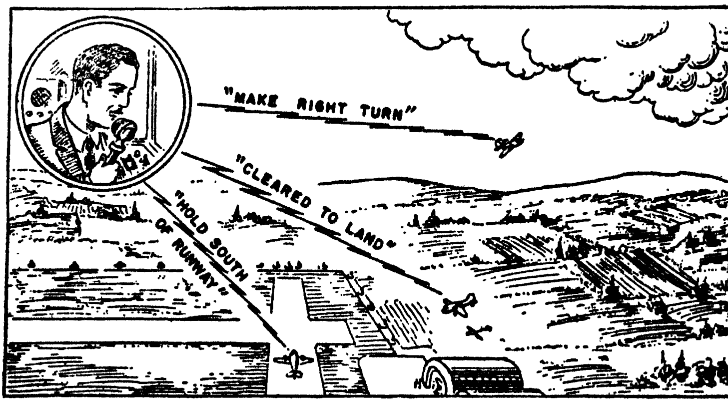


FIG. 141—Airport traffic controller issues instructions to prevent collisions

six, eight, four, seven, four." Air carrier: (abbreviated name of company)—(flight or trip number), e.g.: "United fifteen"; "American six," etc. Note: Air carrier flight or trip numbers are spoken as a group figure instead of a serial number, as in the case of other aircraft identification numbers. The name of the pilot should not ordinarily be used in routine two-way communication.

Call-up procedure shall consist of the following:

Item	Example
(a) Designation of station (aircraft) called	Waco one eight one four three
(b)	This is
(c) designation of calling station	Cleveland Tower
(d) invitation to reply	Over

The reply to an initial call-up shall consist of:

Item	Example
(a) Designation of station called	Cleveland Tower
(b)	This is
(c) designation of answering station	Waco one eight one four three
(d) invitation to reply	Over

Communication shall be initiated by call-up and reply when (a) communication has not been established, (b) previous contact has been terminated. After contact has been established, a second call-up, followed by the message, should be made, as follows:

Item	Example
(a) Designation of station called	Waco one eight one four three
(b)	This is
(c) designation of calling station	Cleveland Tower
(d) body of the communication	(Message)
(e) invitation to reply	Over

If it is reasonably certain that the aircraft will receive the initial call-up, the traffic controller may follow the first call-up with a message without waiting for a reply from the aircraft. But a pilot should remember that a control tower may be receiving messages from several aircraft simultaneously, and he should always receive an invitation to reply (over) from the tower before proceeding.

The aircraft shall acknowledge receipt of a radiotelephone message by transmitting the aircraft identification, followed by the word "Roger." The word "out" shall also be used when a conversation is ended. Example: "Stinson four two three one five, Roger, out."

The word "wilco" (meaning will comply) shall be used to indicate that the receiving station will comply with instructions or requests. When used, this will take the place of the acknowledgment "Roger." Example: "Fairchild three six seven zero one, wilco, out."

The phrase "say again," to indicate that the message has not been

received, and the word "wait," to indicate that a return call will be made, may be substituted for the word "Roger."

Figures used to indicate ceiling heights, flight levels, and upper air levels, in numbers smaller than twelve thousand, shall be spoken in even hundreds and thousands of feet. These figures in the number 13,000, and larger numbers, shall be spoken, as, for example, "one three thousand."

Number	Expression
500	Five hundred
1,300	One thousand three hundred
4,500	Four thousand five hundred
12,000	Twelve thousand
13,000	One three thousand

All serial figures, such as aircraft identification numbers (except air carrier flight numbers), shall be spoken individually, as follows:

Number	Expression
18143	One eight one four three
26075	Two six zero seven five

Time shall be stated in four figures, on the twenty-four-hour clock basis. The hour shall be stated by the first two figures, and the minutes by the last two figures, as follows:

Time	Expression
0000 (midnight)	zero zero zero zero
0920 (9.20 a.m.)	zero nine two zero
1200 (noon)	one two zero zero
1643 (4.43 p.m.)	one six four three

Time may be stated in minutes only (two figures) in airport traffic control communications when no misunderstanding of the hour is likely. The twenty-four-hour clock day begins and ends at 0000 (midnight). The last minute of the last hour begins at 2359 and ends at 0000, which is the beginning of the first minute ending at 0001 of the first hour of the next day.

Field elevations shall be stated in feet in accordance with the following examples:

10 ft.—field elevation one zero
75 ft.—field elevation seven five
583 ft.—field elevation five eight three
600 ft.—field elevation six hundred
1,850 ft.—field elevation one eight five zero
2,500 ft.—field elevation two thousand five hundred

Departing and Arriving

When the pilot is ready to taxi out, he shall call the control tower. Body of his message should include: "Ready to taxi. Departing for (destination or nature of flight)," or, "Here is my flight plan" (if flight plan has not been previously submitted). Example:

Aircraft: "Tulsa Tower, this is Waco one three one five nine. Ready to taxi. Departing for St. Louis. Over."
Tower: "Waco one three one five nine cleared to runway three six. Wind North eight. Altimeter three zero zero four. Time zero nine, five six."

If an airway traffic control clearance is necessary, the airport traffic controller will relay the clearance to the pilot, as follows:

Tower: "Waco one three one five nine ATC clears you to Neosho to cruise at five thousand feet. Over."
Aircraft: "Waco one three one five nine cleared to Neosho to cruise at five thousand. Wilco. Over."
Tower: "Waco one three one five nine. Roger."

After the ATC clearance has been issued and acknowledged, the controller will issue the take-off clearance:

Tower: "Waco one three one five nine, local traffic American Douglas three miles east at seven hundred landing Tulsa. Cleared for take-off. Over."
Aircraft: "Waco one three one five nine, Roger. Out."

The pilot should continue to listen on the control tower frequency until permission to change has been received. If such permission is not received, the pilot may change over to radio range frequency when he leaves the airport control zone.

An arriving aircraft should call the control tower for local traffic information and landing instructions, when fifteen miles from airport of destination, if on contact flight. If not on contact, pilot should call as soon as ground contact is established. The body of the message should include:

(a) geographical position, (b) time (optional), (c) flight altitude of aircraft, (d) contemplated course, if flight not in accordance with approved flight plan, and (e) request for information or instructions. Example: Aircraft: "Cleveland Tower, this is Stinson one four one five seven, Elyria two five at three thousand, landing at Cleveland. Over."

The controller will acknowledge this, and will issue a clearance to enter traffic pattern. This clearance informs the pilot that traffic exists in the traffic pattern (otherwise the aircraft would have been cleared to land), and authorizes entry into traffic pattern. Wind information and number of runway in use are included to assist pilot in making his approach for entry into traffic pattern, but clearance to land is ordinarily withheld until the aircraft is in sight of the control tower, and no conflicting traffic will interfere with the landing. Example:

Tower: "Stinson one four one five seven, Elyria two five at three thousand. Cleared to enter traffic pattern. Wind south one four. Runway one eight. Over."

Aircraft: "Stinson one four one five seven, Roger."

The pilot should report to the controller immediately on entry into traffic pattern, if the controller has not previously sighted the aircraft and issued landing instructions. The pilot reports: "Cleveland Tower, this is Stinson one four one five seven. Three miles west of field at eight hundred. Over." The tower replies by issuing a landing clearance, if practicable, or suitable instructions: "Stinson

one four one five seven, three miles west of field at eight hundred. Cleared to land. Make right turn in."

After a pilot has landed, the traffic controller will furnish information on other aircraft landing or taking off, and issue necessary instructions relative to taxying. This control will be continued until the pilot has parked his aircraft. Example:

Tower: "Stinson one four one five seven cleared to gate three."
Aircraft: "Stinson one four one five seven, Roger."

The control tower operator will initiate calls to inbound aircraft which have not called the tower, as soon as they are observed.

Airway Traffic Control

Whenever an aircraft is being operated in weather conditions equal to or better than the minimums prescribed for contact flight, the flight shall be considered to be operating in "Contact Flight Rule" weather conditions.

A Contact Flight Rule flight plan may be submitted to the nearest airway traffic control center, airport traffic control tower, or airway communications station, by person, telephone, or radio, and shall contain the following items:

(1) Identification of aircraft and pilot. Example: Waco NC1234, Pilot Smith. (2) Time and point of departure. Example: Departed St. Louis at 1405. (3) Proposed cruising altitude or altitudes. Example: Contact Flight Rules (CFR); or 4000, Contact Flight Rules (4000/CFR). (4) Proposed route to be followed. Example: Via Kansas City. (5) Destination and estimated time of arrival. Example: Wichita at 1655. (6) Usable radio equipment carried. Example: 3105 (transmitter frequency) receiver only, no radio. (7) Number of aircraft making flight if they are to be flown in formation.

In connection with item (3), a pilot may submit two types of altitude information in a contact flight rule plan, as follows: A contact flight rule flight plan may contain CFR (contact flight rules) or specific altitude levels followed by CFR, indicating that it is

proposed to conduct the flight in accordance with contact flight rules specified in Part 60 of the C.A.R. No traffic clearances for the exercise of control will be issued by an airway traffic control center to a pilot submitting this type of altitude information. The only

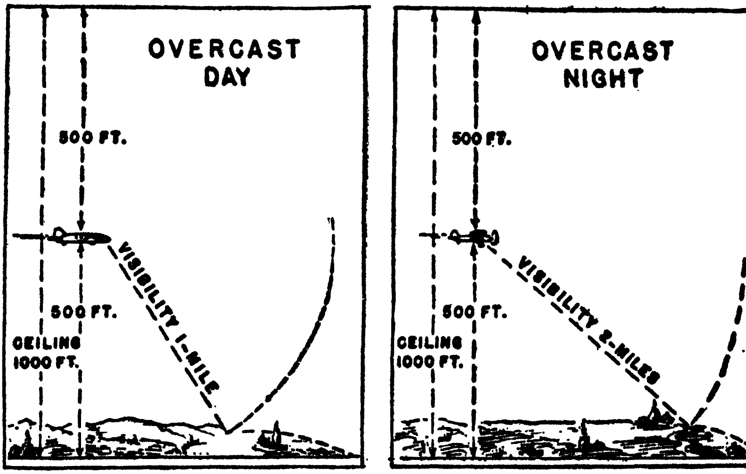


FIG. 142—Ceiling and visibility minimums for contact flight rules flight above 1,000 feet altitude

report required is an arrival report, unless the pilot indicates, at the time of filing the flight plan, that an arrival report will not be filed. Arrival reports will be forwarded by CAA communication channels when available.

Ceilings and Visibility

Aircraft must be flown at least 500 feet above the terrain and at least 500 feet below the overcast; therefore a minimum ceiling of 1,000 feet is required at all times. For flight below 1,000 feet above terrain, a minimum visibility of one mile by day and two miles at night is required. For flight above 1,000 feet above terrain, a visibility of three miles is required at all times. For flight within the control zone of a control airport, a visibility of three miles is re-

quired at all times, unless a certificated control tower operator authorizes flight under conditions of lower visibility.

The filing of a Contact Flight Rule flight plan is required whenever a night flight or a formation flight is to be made within an airway traffic control area. Except for necessary ascent and descent,

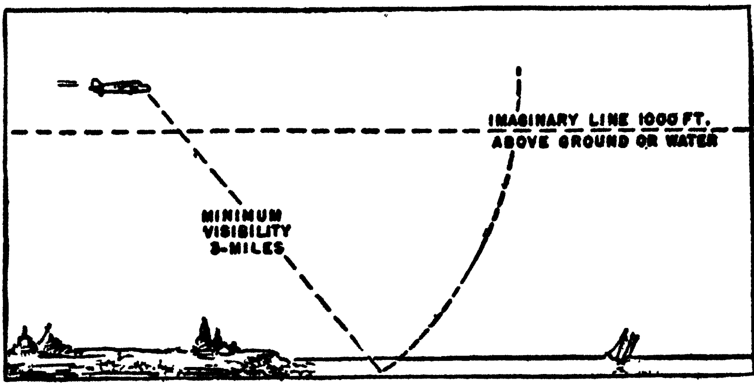


FIG. 143—Visibility minimum for contact flight rules flight above 1,000 feet altitude

aircraft flying along or across the civil airways under contact flight rules are required to maintain proper flight altitudes relative to the direction of flight and color of the airway involved.

INSTRUMENT FLIGHT RULES

Contact flight rules apply to flight of aircraft when pilots can see and be seen. Instrument flight rules apply when a pilot cannot see and be seen sufficiently to proceed under contact flight rules.

Each airway traffic control center has under its jurisdiction certain portions of the civil airways, known as its control area. Before an aircraft can depart from or enter an airway traffic control area, certain requirements must be met. For flight subject to instrument flight rules, pilot and aircraft must be properly rated and equipped for flight by instruments. One of the requirements is that the aircraft be equipped with a working two-way radio.

Prior to departure from or on entering an airway traffic control area, a pilot must submit to an airway traffic control center, either in person, by telephone, or by radio, a flight plan, and obtain approval therefor. The filing of an instrument flight plan indicates that the pilot is qualified, and the aircraft equipped for flight in

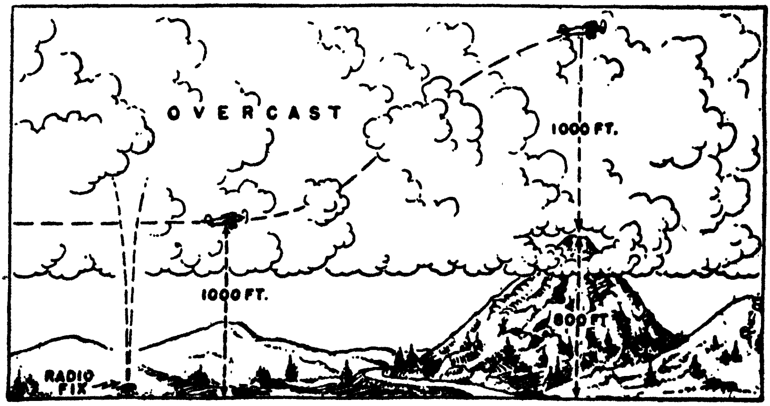


FIG. 144—Minimum instrument flight altitudes

accordance with instrument flight rules, and that the pilot will conform to all its provisions. It shall contain:

(1) The aircraft identification mark, or name of air carrier operator and trip number. Examples: "NC12345"; "United, trip 7."
(2) The number of aircraft making the flight, if the aircraft are in formation, the over-all area to be occupied, and the type of aircraft. Example: "3 Stinson."
(3) The name of pilot or flight commander. Example: "Jones."
(4) Point of departure or position of aircraft if flight plan is filed en route.
(5) Proposed cruising altitude above sea level, and route of flight. When altitude over a fix will differ from cruising altitude, such information also should be included. Example: "Cruising 5000 via Philadelphia, crossing Newark at 2000."
(6) Point of first intended landing.
(7) Proposed cruising air speed in miles per hour.

(8) Radio transmitting frequency to be used on flight. Example: "3105."

(9) Proposed time of departure (time when the aircraft leaves the ground).

(10) Estimated elapsed flying time in hours and minutes until arrival on the ground at the point of first intended landing. Example: "Estimated elapsed time three hours, thirty-five minutes."

(11) The alternate airport, if the operation is to involve instrument flight.

(12) Any other pertinent information which the pilot deems useful for control purposes, or which is requested by airway traffic control center.

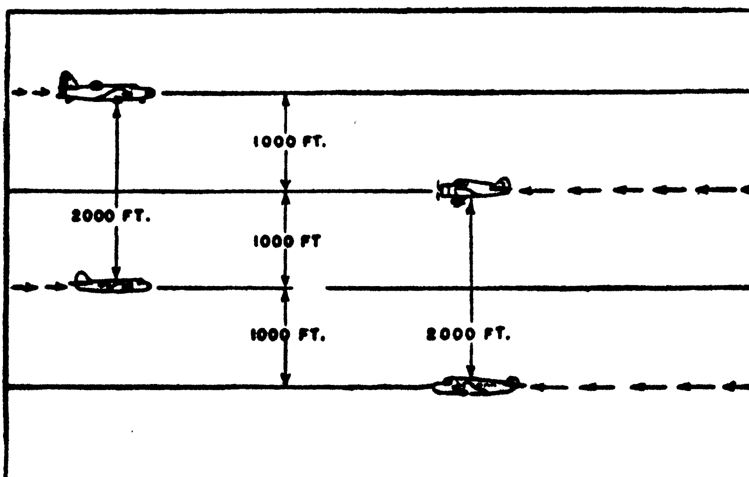


FIG. 145—Vertical separation for instrument flight rules flight plan

In connection with item (5), a pilot may submit two types of altitude information in an Instrument Flight Rule flight plan, as follows:

(a) Specified altitude levels above sea level, depending upon the color of the airway to be flown, and the direction of flight. (b)

Above may be supplemented by use of the words "contact or," as "contact or 3,000." This indicates that the pilot desires to maintain contact flight as long as possible, and when such contact flight is no longer possible because of weather and minimum altitude restrictions, he will climb to the alternate instrument altitude specified in the flight plan. This specified altitude level shall normally be the minimum safe instrument flight altitude for the terrain over which the flight will be made.

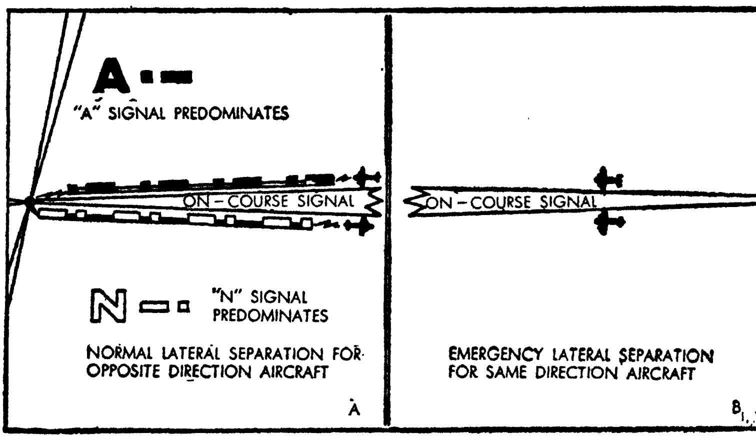


FIG. 146—Lateral separation for instrument flight rules flight plan

Approval of flight plan will be in the form of a traffic clearance, indicating the extent of the control area over which the flight plan is approved. It will include any necessary amending traffic control instructions, together with essential traffic information, if requested by the pilot. Such traffic clearances are always issued in standard phraseology, commencing with "ATC clears you," or "ATC advises," etc.

Flight plans cannot be considered as approved unless the clearance is preceded by this prefix. Prior to or upon reporting over the clearance point, the pilot must receive further traffic clearance to another point if flight is to continue on approved flight plan. The pilot of an aircraft leaving one airway traffic control area and en-

tering another will be, "cleared from (specified location) to —— miles —— (direction of) —— (location)," indicating the boundary between two airway traffic control centers. Further clearance must be secured prior to entering the adjacent airway traffic control area.

Once a flight has entered an airway traffic control area, no change can be made in the approved flight plan, except in emergency, without first obtaining approval from the airway traffic control center having jurisdiction. In addition to altitude and course changes, increasing or decreasing the speed of an aircraft by increasing or decreasing power constitutes a change in flight plan. The pilot of an aircraft flying within an airway traffic control area, prior to effecting such change in flight plan, shall obtain approval from the airway traffic control center.

An approach clearance is an approval for one approach only, and additional approaches constitute a change in flight plan.

Altitude Requirements

Regulations prescribe that flight altitudes shall be in feet above sea level. Accordingly, altimeters should be adjusted to the current setting of the nearest station reporting official altimeter settings along the route of flight. All sea-level altitudes used in connection with the control of air traffic are based on the indicated altitude, since any temperature error will affect all altimeters in that area to the same extent, and relative separation between aircraft will be maintained. Altimeter setting is defined as the setting to be made to the barometric scale of an altimeter, so that, upon landing, the instrument will indicate the actual elevation of the airport above sea level.

Aircraft flying on instruments in the overcast must be at least 1,000 feet above terrain. Aircraft must be flown at prescribed even or odd thousand-foot levels above sea level, depending on the color of the airway and direction of flight, unless other altitudes are assigned or approved by an airway traffic control center.

Airway traffic control centers effect separation of aircraft, verti-

cally, by assigning different altitude levels; horizontally, by prescribing a minimum flying time between aircraft; and laterally, by providing for different flight paths. All instructions from an airway traffic control center are transmitted through radio range stations, airport traffic control towers, and radio stations of aircraft operators.

During the progress of a flight, pilots are required to make "flight progress reports," which include time and altitude over designated radio fixes on the route being flown. In addition, pilots are required to observe the following reporting procedures when flying within an airway traffic control area: Include in each report an estimated time of arrival over the next designated radio fix; forward an estimated time of arrival and requested altitude over the radio fix preceding the airport of intended landing, and estimated time of arrival when reporting over the second fix preceding such airport.

Weather reports by the pilot need be forwarded to an airway traffic control center only when requested, or when pilot encounters unanticipated or unusual weather conditions, such as icing conditions, turbulence, etc.

The following communications contacts are required to be made by the pilot, under instrument flight rule conditions, in addition to en-route reports: (1) Report time and altitude of reaching a specified holding point or fix to which cleared. (2) Report when vacating any previously assigned flight level for a new assigned flight level. (3) Report when leaving any assigned holding point. (4) Report, on request, when making procedure turn on final approach. (5) Report, on request, when over range station on final approach. (6) Report, on request, when ground contact is established. (7) Report when an approach for landing has been missed, and request further instructions. (8) Report, on request, when passing through 1,000-foot levels while descending or climbing. (9) Report, on request, when attaining cruising altitude.

Upon receipt of advice that an aircraft in flight has encountered an emergency which may affect other aircraft, the control center concerned will provide the aircraft in emergency with priority over any other aircraft. Should it become necessary for an aircraft, while

holding, to make an emergency descent for a landing through other traffic, the pilot of that aircraft should so advise the airway traffic control center concerned. Upon receipt of such notice, the controller will immediately broadcast, on radio-range frequency, the following: "Emergency to all concerned emergency landing at —— airport. All aircraft below —— thousand feet within —— miles of —— radio range leave —— legs immediately."

Upon receipt of such broadcast, pilots of aircraft affected should clear the specified areas. The airway traffic controller will issue further instructions immediately following the emergency broadcast.

Holding instructions issued by an airway traffic control center will specify the limits. Holding aircraft shall follow the right edge of the on-course signal of the appropriate leg of the radio range. Turns may be made as desired, unless specifically instructed by the ATC center to make turns in a specified quadrant.

If landing is not completed in fifteen minutes (or the time allowed for a standard instrument approach) after passing over the radio range station on the initial approach, or within fifteen minutes after being issued approach clearance under conditions of approach sequence assignment, a pilot shall obtain further instructions from the ATC center. The control center then will allow the pilot another immediate attempt, or instruct him to stand by on a designated leg of the range at a certain altitude until other aircraft in line have landed or taken off. This decision will be based upon existing conditions such as remaining fuel, weather trend, etc.

The pilot is responsible for filing an arrival report on a flight for which a flight plan has been filed. The arrival report should be filed with the communication station at point of destination, or on landing if flight has been terminated at an intermediate point. If CAA facilities are not available, commercial wire or telephone should be used. If the report of arrival, or of cancellation of the flight at an intermediate point, is not received within a reasonable period after the estimated time of arrival, the aircraft will be traced by inquiry at intermediate stations. An unreported aircraft is maintained on the flight progress boards in an ATC center, or CAA airport traffic

control tower, for thirty minutes after estimated time of arrival. During this time, other aircraft movements may be restricted or suspended to prevent possibility of collision. Should the aircraft still be unreported after thirty minutes, the ATC center may resume normal traffic, after all concerned have been notified. Failure to complete flight plan with an arrival report may subject the pilot to a civil penalty.

Glossary

Approach Clearance—The permit issued to a pilot making a flight, subject to instrument flight rules authorizing an approach for landing.

Approach Sequence—A priority schedule specifying the sequence of approach of aircraft at a given point.

Approach Time—The time at which the approach may be commenced.

ATC—An abbreviation of Airway Traffic Control or Airway Traffic Control Center.

Essential Traffic Information—Information on aircraft which are expected to be overtaken, passed, or approached within less than fifteen minutes of actual flying time, when such aircraft are 2,000 feet or less vertically above or below the aircraft being cleared.

Flight Plan, Contact Flight Rule—A flight plan containing the information specified in Part 60 when filed for a flight in accordance with contact flight rules.

Flight Plan, Instrument Flight Rule—A flight plan containing the information specified in Part 60 when filed for a flight in accordance with instrument flight rules.

Local Traffic—Aircraft operating in the traffic pattern of the landing area concerned.

Runway in Use—The runway currently in use by aircraft landing and taking off with existing wind conditions, or as indicated by the airport traffic controller, if calm wind conditions exist.

Separation, Altitude—The method of effecting separation of aircraft in flight, accomplished by the assignment of different altitude levels.

Separation, Lateral—The method of effecting separation of aircraft flying in opposite directions, along a well-defined radio range course, and on opposite sides of such course.

Separation, Time—The method of effecting separation of aircraft in flight, accomplished by requesting the pilot of an aircraft either to lose time so that he will arrive over a specified fix at a specified time, or to hold over a specified fix for a specified time.

Tower—An airport traffic control tower; i.e., an elevated control room so situated and equipped that its operator can adequately control air traffic in the immediate vicinity of an airport at which the tower is located.

Taxi Patterns—The desired movement of aircraft on the ground at the landing area during specified wind conditions.

Traffic Clearance—An authorization issued by an airway traffic control center or an airport traffic control tower, to fly an aircraft solely with respect to known air traffic conditions, including flight plan approval and traffic control instructions (flight plan amendments).

Traffic Patterns—The desired flow of aircraft flying contact below 1,500 feet above ground in the vicinity of an airport, or other landing area, during specified wind conditions.

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